Attorney Docket Number: FY.51395US0A
Applicant: Fujii et al.
Title: INTELLIGENT ROBUST CONTROL SYSTEM FOR MOTORCYCLE USING SOFT COMPUTING OPTIMIZER
Application Number: 10/792,292

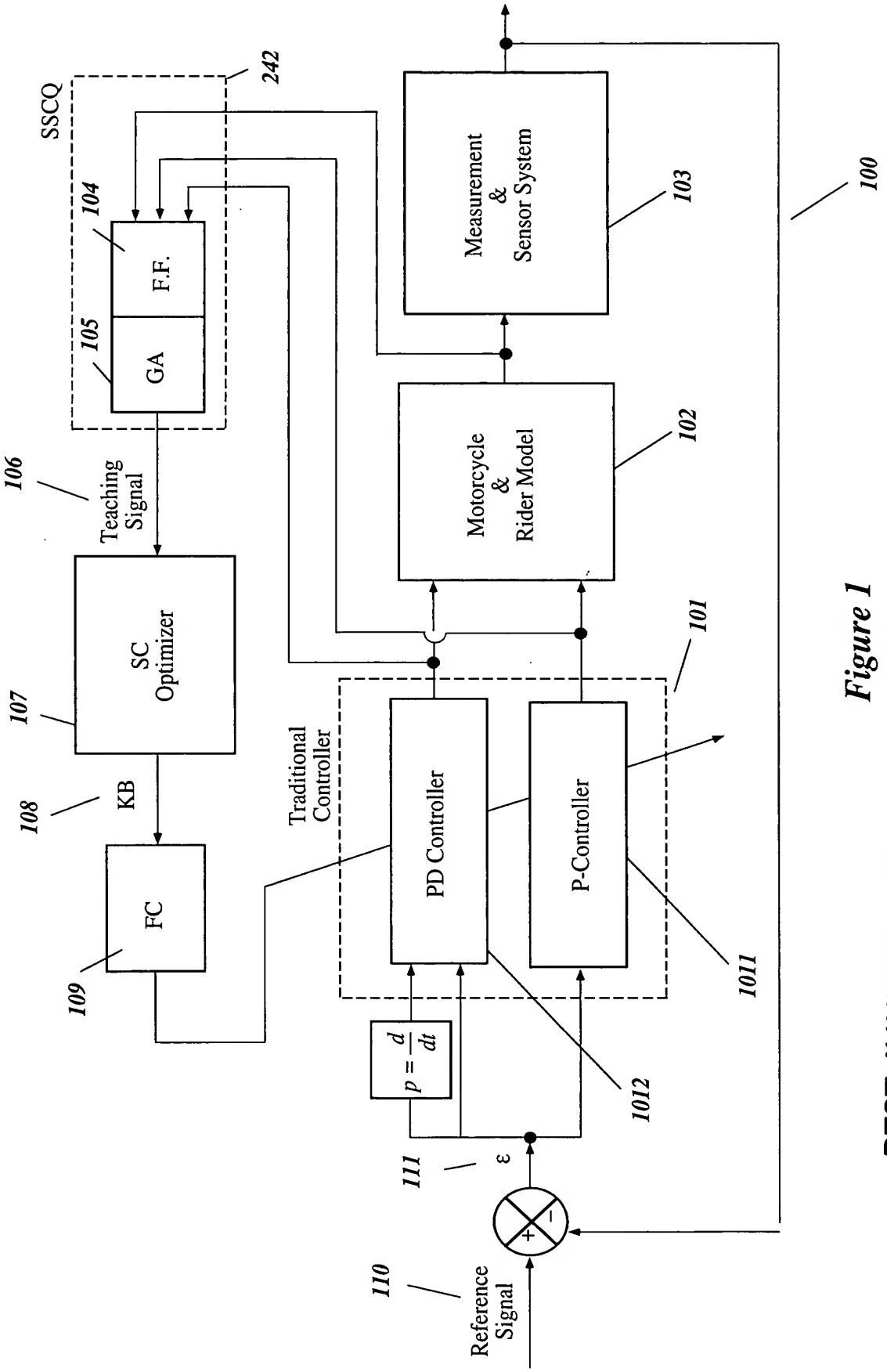
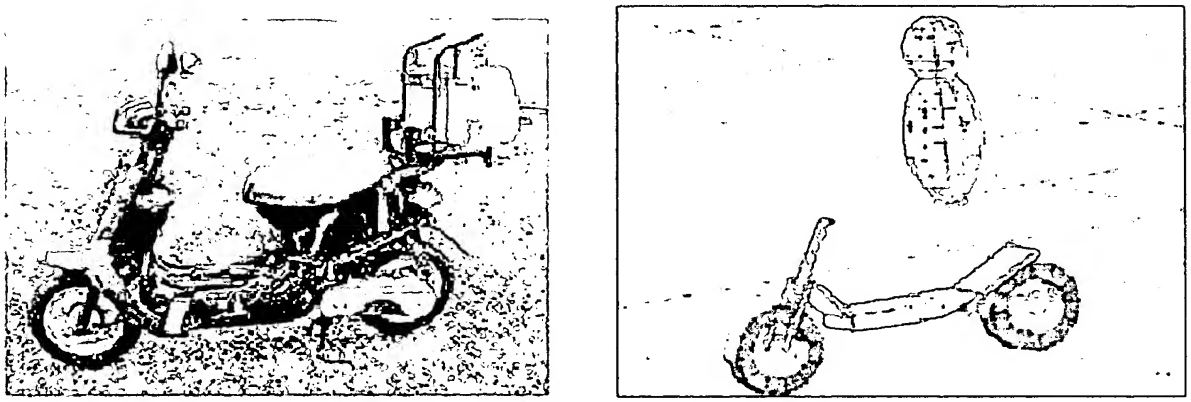


Figure 1



(a) (b)

Figure 2

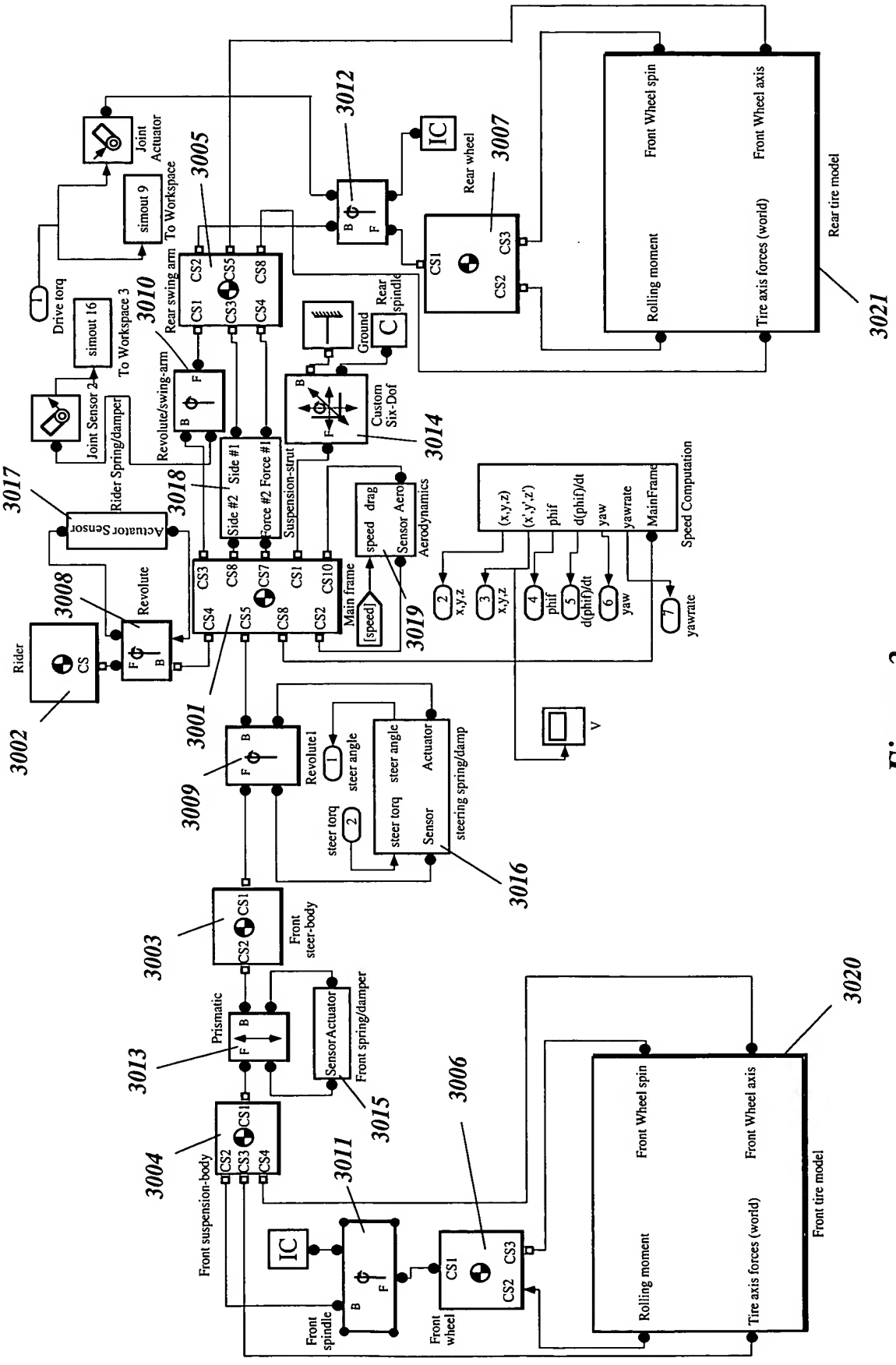

3002
3001
3003
3004
3005
3006
3007
3008
3009
3010
3011
3012
3013
3014
3015
3016
3017
3018
3019
3020
3021
Rider
CS
Revolute
Actuator Sensor
Joint Actuator
simout 9
To Workspace
Drive torq
simout 16
To Workspace 3
Joint Sensor 2
Rider Spring/damper
Rear swing arm
Revolute/swing-arm
Ground
Rear spindle
Rear wheel
IC
Custom Six-Dof
Side #1
Side #2
Force #2
Force #1
Suspension-strut
Main frame
[speed]
speed
drag
Sensor
Aero
Aerodynamics
(x,y,z)
(x',y',z')
phif
d(phif)/dt
yaw
yawrate
MainFrame
Speed Computation
x,y,z
phif
yaw
yawrate
Revolute1
steer angle
steer torq
Actuator
steering spring/damp
Front steer-body
Prismatic
Sensor
Actuator
Front spring/damper
Front suspension-body
Front spindle
Front wheel
Front Wheel spin
Front Wheel axis
Rolling moment
Tire axis forces (world)
Rear tire model
Front tire model
V

Figure 3

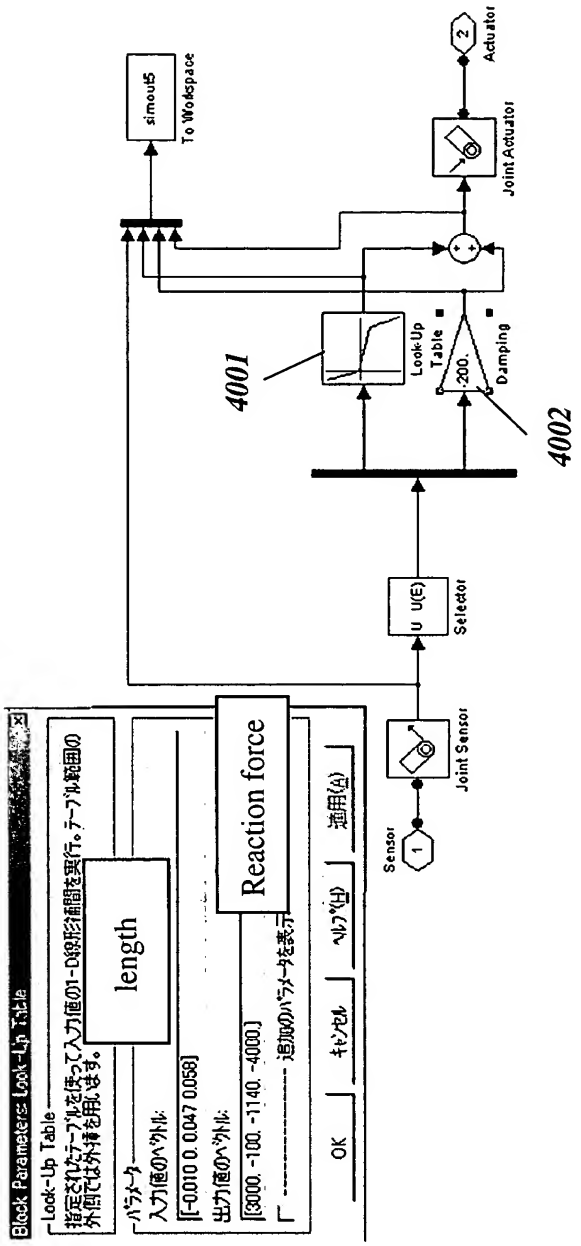

Block Parameters: Look-Up Table
Look-Up Table
length
Reaction force
OK
simout5
To Workspace
Actuator
Joint Actuator
Look-Up Table
Damping
200.
4001
4002
U U(E)
Selector
Joint Sensor
Sensor

Figure 4

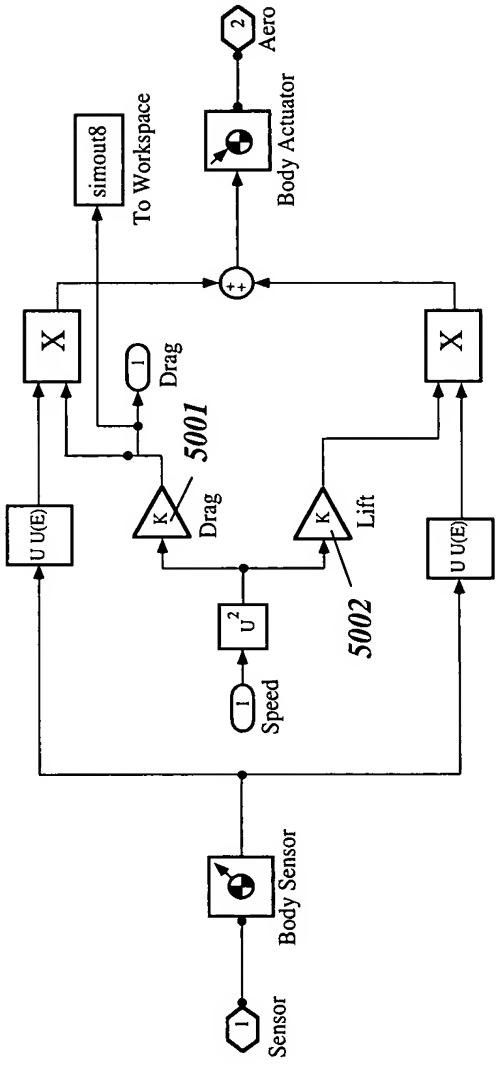
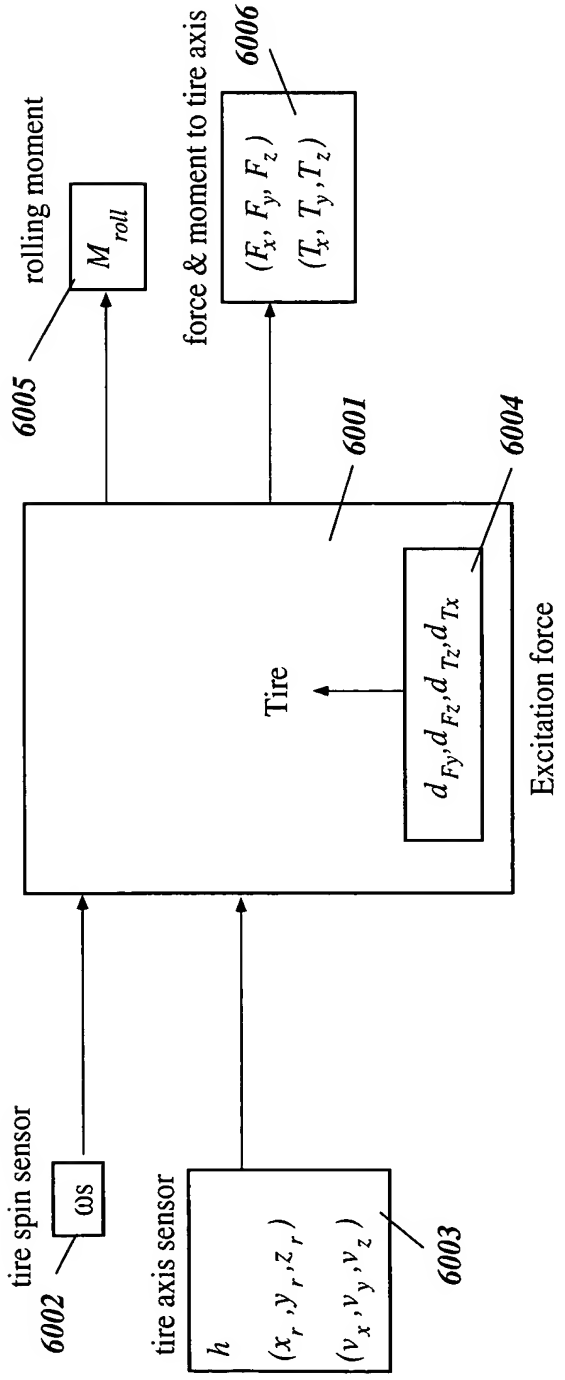

2
Aero
Body Actuator
simout8
To Workspace
++
X
X
1
Drag
5001
K
Drag
K
Lift
U U(E)
U U(E)
U^2
5002
1
Speed
Body Sensor
1
Sensor

Figure 5


rolling moment
M_{roll}
6005
force & moment to tire axis
6006
(F_x, F_y, F_z)
(T_x, T_y, T_z)
6001
6004
Tire
$d_{Fy}, d_{Fz}, d_{Tz}, d_{Tx}$
Excitation force
tire spin sensor
ωs
6002
tire axis sensor
h
(x_r, y_r, z_r)
(v_x, v_y, v_z)
6003

Figrue 6

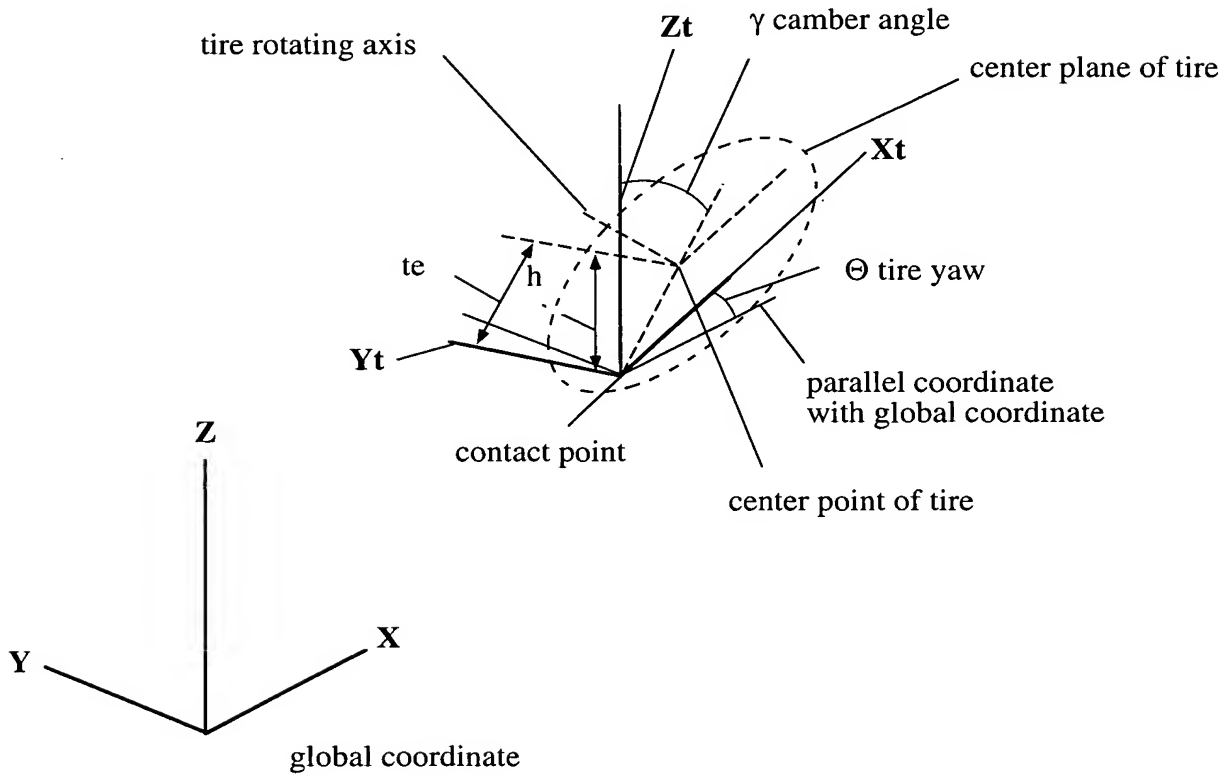
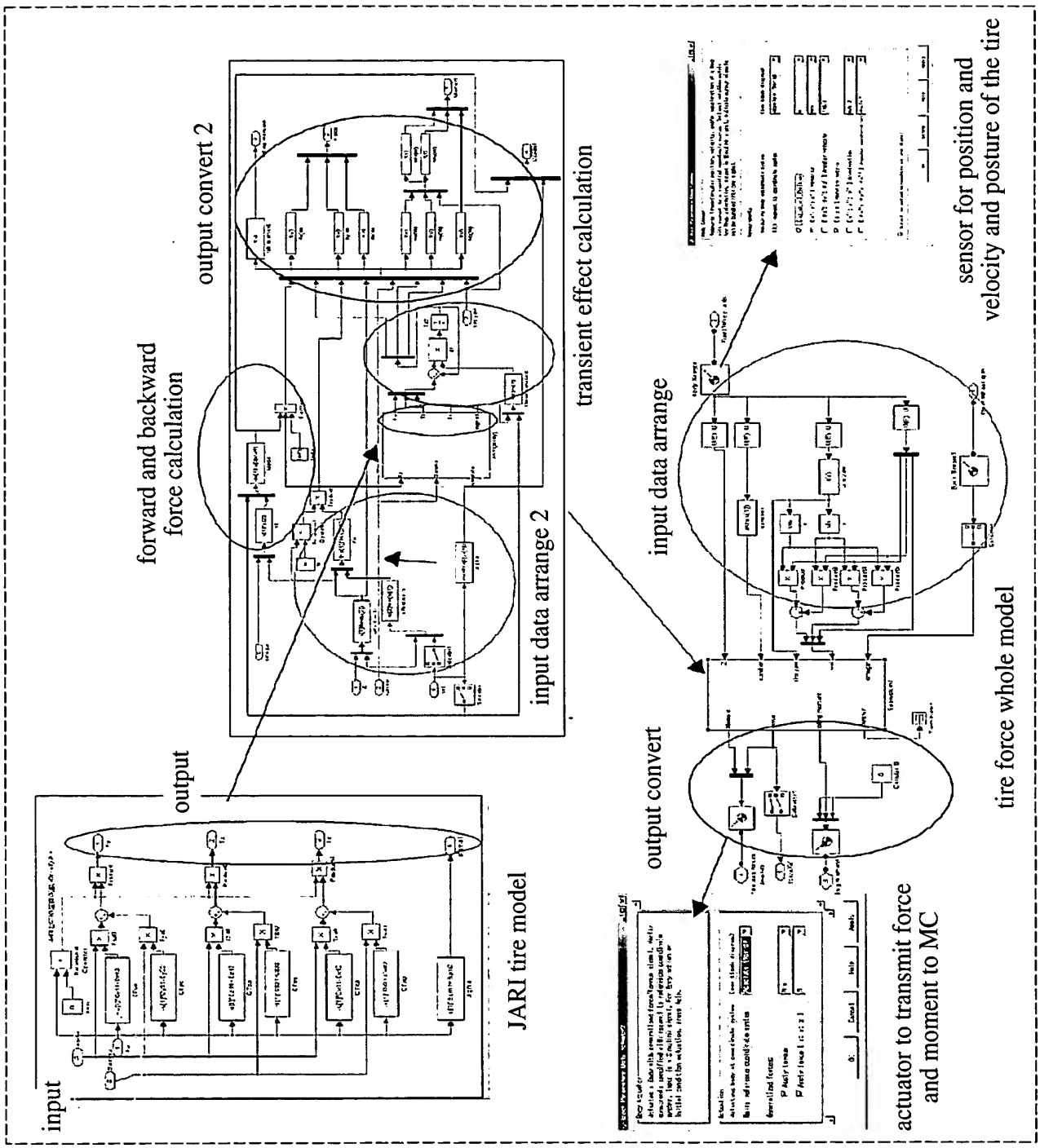

tire rotating axis
Zt
γ camber angle
center plane of tire
Xt
te
h
Θ tire yaw
Yt
parallel coordinate
with global coordinate
contact point
center point of tire
Z
Y
X
global coordinate

Figure 7


input
output
JARI tire model
forward and backward
force calculation
output convert 2
input data arrange 2
transient effect calculation
output convert
input data arrange
actuator to transmit force
and moment to MC
tire force whole model
sensor for position and
velocity and posture of the tire
(b)

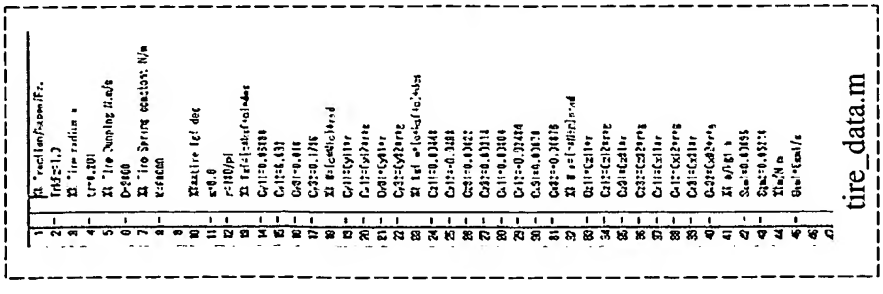

tire_data.m
(a)

Figure 8

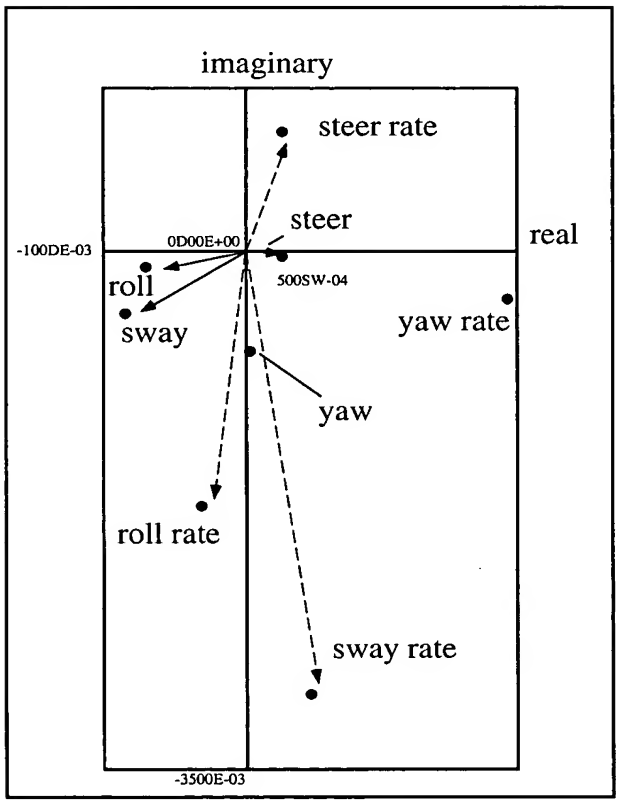

imaginary
steer rate
steer
real
-100DE-03
0D00E+00
500SW-04
roll
sway
yaw rate
yaw
roll rate
sway rate
-3500E-03

Figure 9

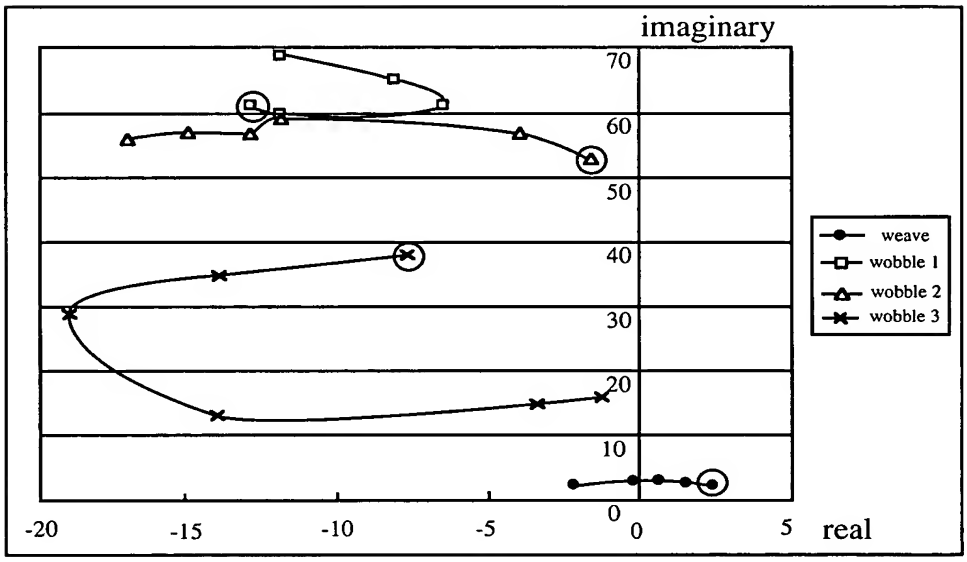

imaginary
70
60
50
40
30
20
10
0
-20
-15
-10
-5
0
5
real
weave
wobble 1
wobble 2
wobble 3

Figure 10

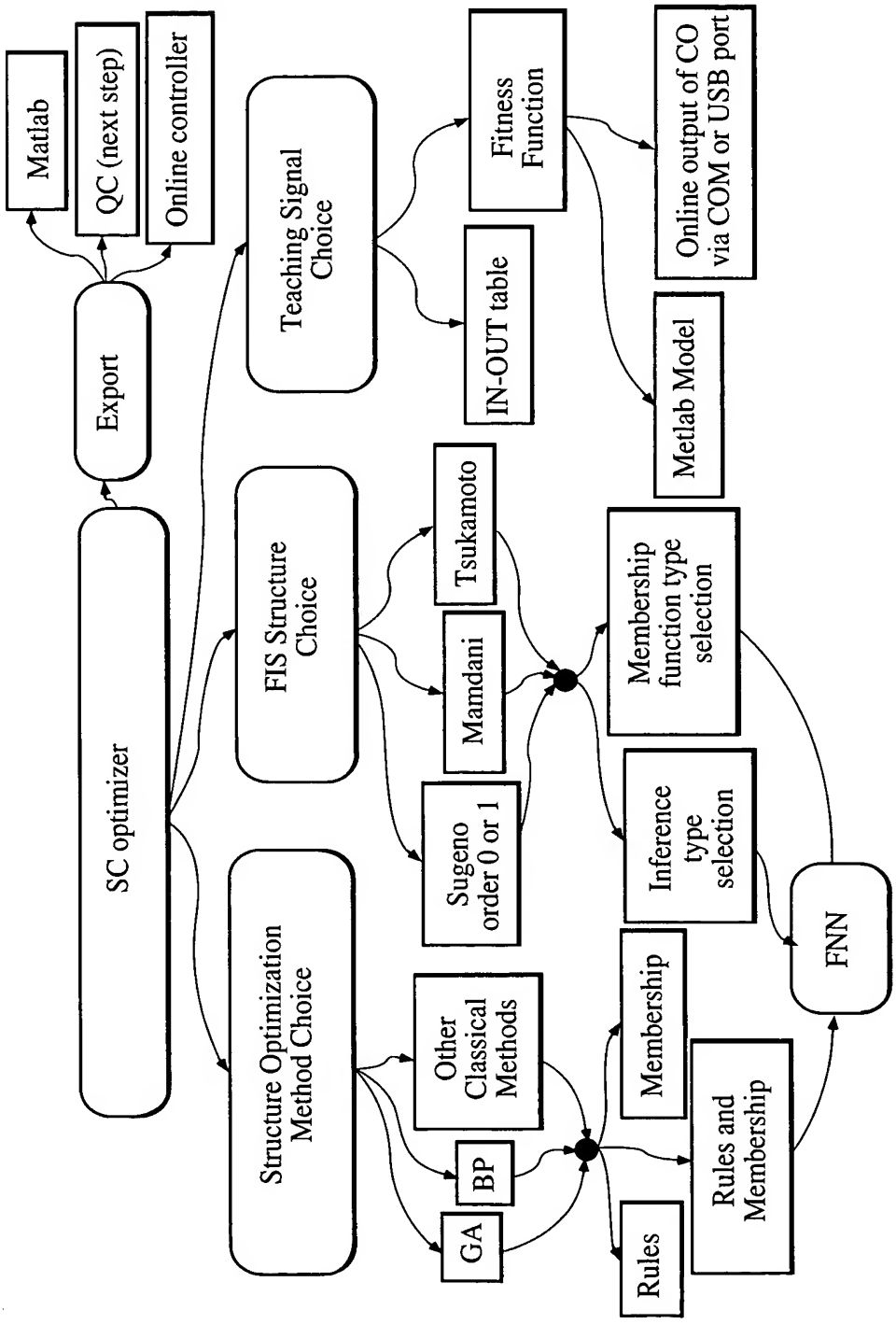

Matlab
QC (next step)
Online controller
Export
SC optimizer
Teaching Signal Choice
Fitness Function
Online output of CO via COM or USB port
IN-OUT table
Metlab Model
FIS Structure Choice
Tsukamoto
Mamdani
Sugeno order 0 or 1
Membership function type selection
Inference type selection
Structure Optimization Method Choice
Other Classical Methods
BP
GA
Membership
Rules
Rules and Membership
FNN

Figure 11

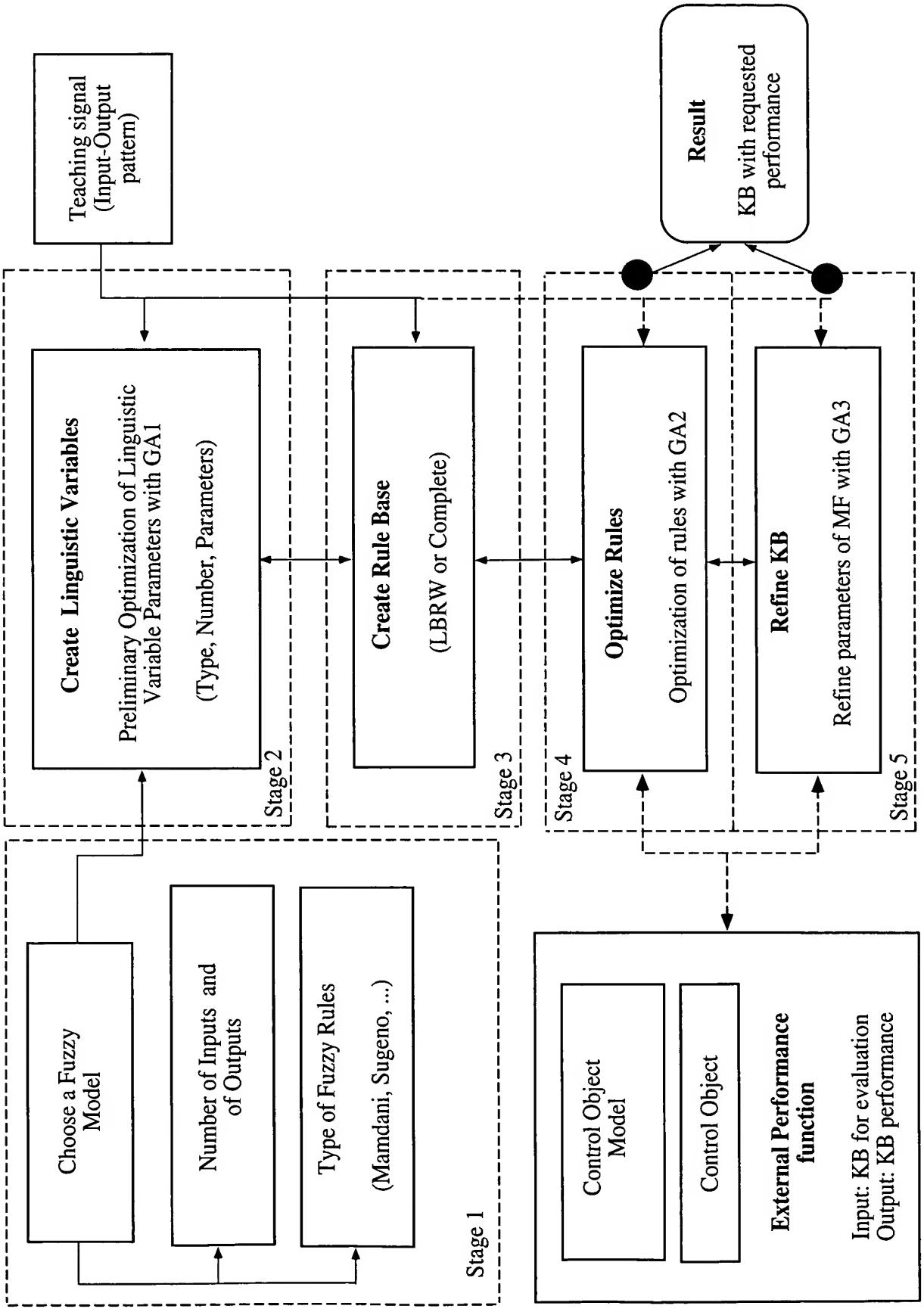

Teaching signal (Input-Output pattern)
Result
KB with requested performance
Create Linguistic Variables
Preliminary Optimization of Linguistic Variable Parameters with GA1
(Type, Number, Parameters)
Stage 2
Create Rule Base
(LBRW or Complete)
Stage 3
Optimize Rules
Optimization of rules with GA2
Stage 4
Refine KB
Refine parameters of MF with GA3
Stage 5
Choose a Fuzzy Model
Number of Inputs and of Outputs
Type of Fuzzy Rules
(Mamdani, Sugeno, ...)
Stage 1
Control Object Model
Control Object
External Performance function
Input: KB for evaluation
Output: KB performance

Figure 12A

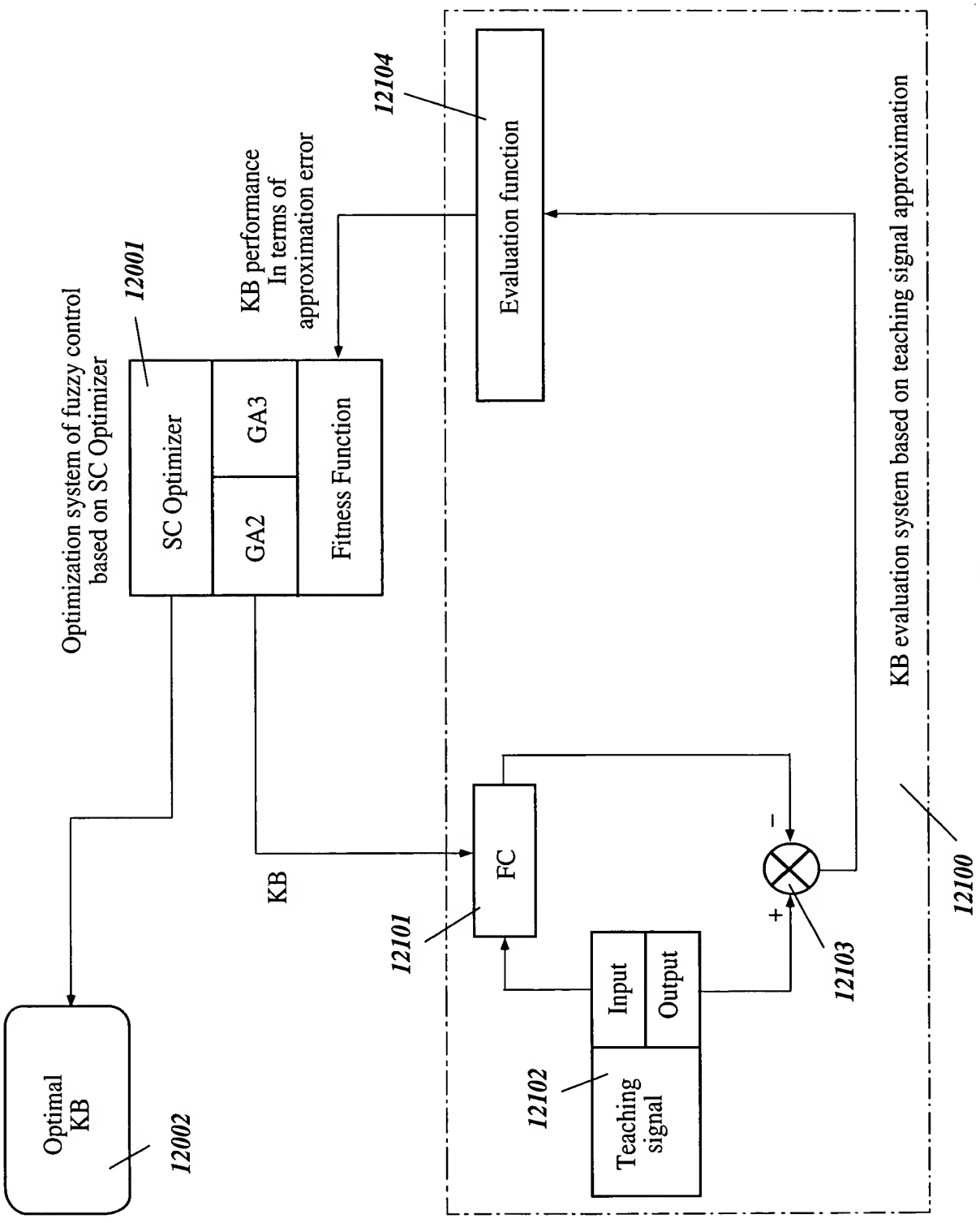

Optimization system of fuzzy control based on SC Optimizer
12001
SC Optimizer
GA3
GA2
Fitness Function
KB performance In terms of approximation error
12104
Evaluation function
KB
FC
12101
Input
Output
Teaching signal
12102
Optimal KB
12002
KB evaluation system based on teaching signal approximation
12100
12103
-
+

Figure 12B

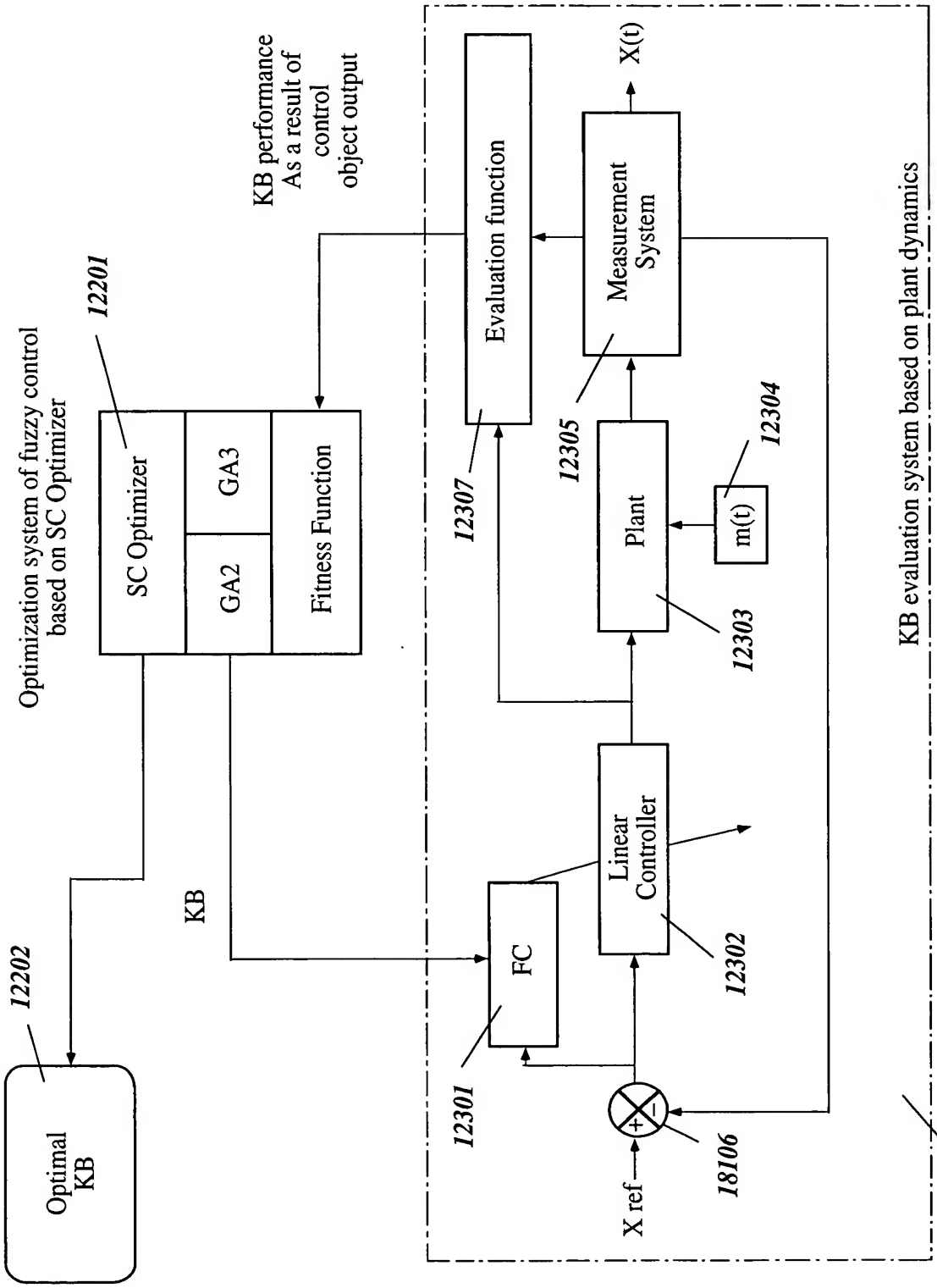

Optimization system of fuzzy control based on SC Optimizer
12201
SC Optimizer
GA3
GA2
Fitness Function
KB performance As a result of control object output
Evaluation function
X(t)
Measurement System
12307
12305
Plant
m(t)
12304
12303
KB evaluation system based on plant dynamics
KB
12202
Optimal KB
FC
Linear Controller
12302
12301
18106
X ref
12300

Figure 12 C

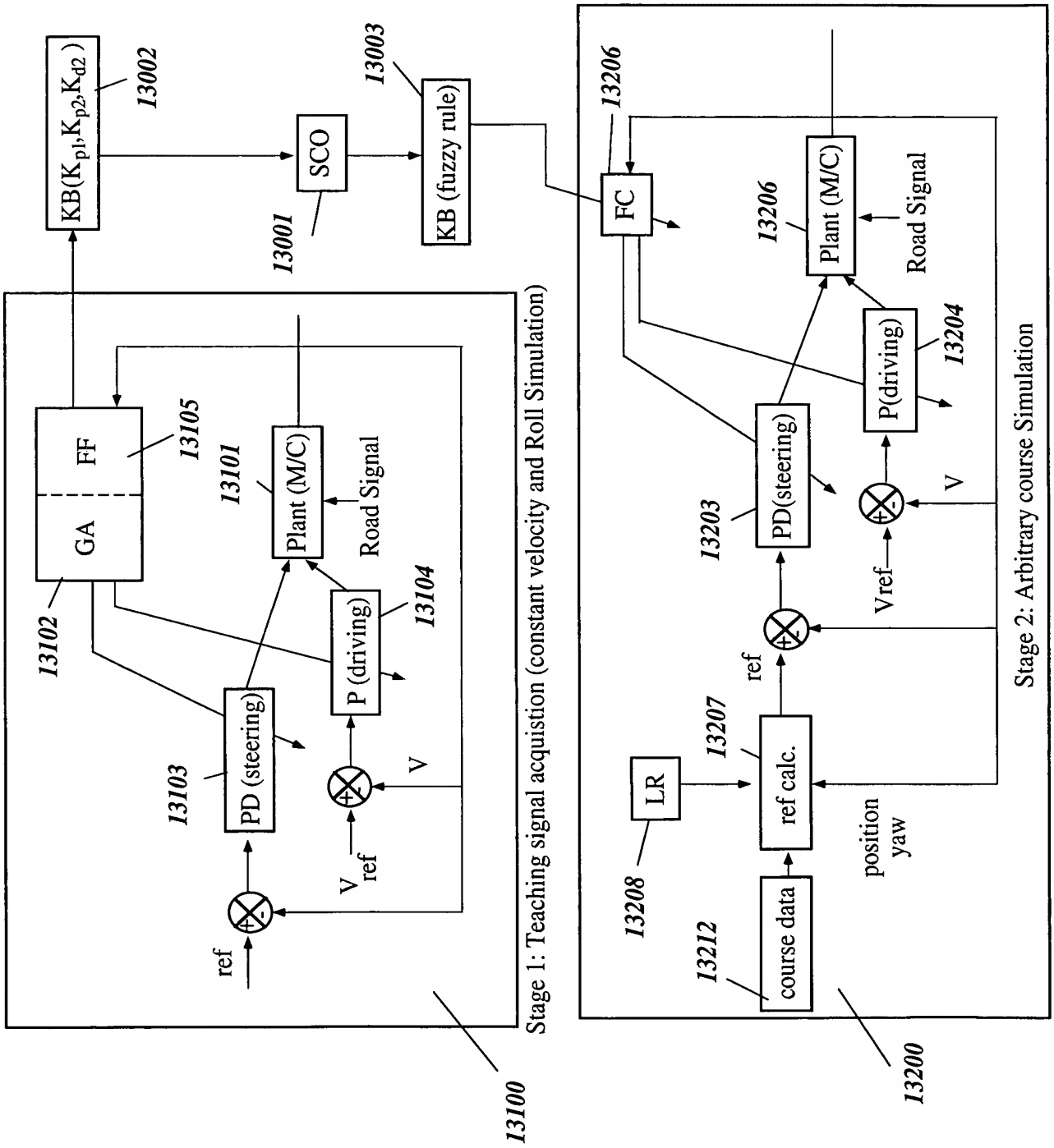
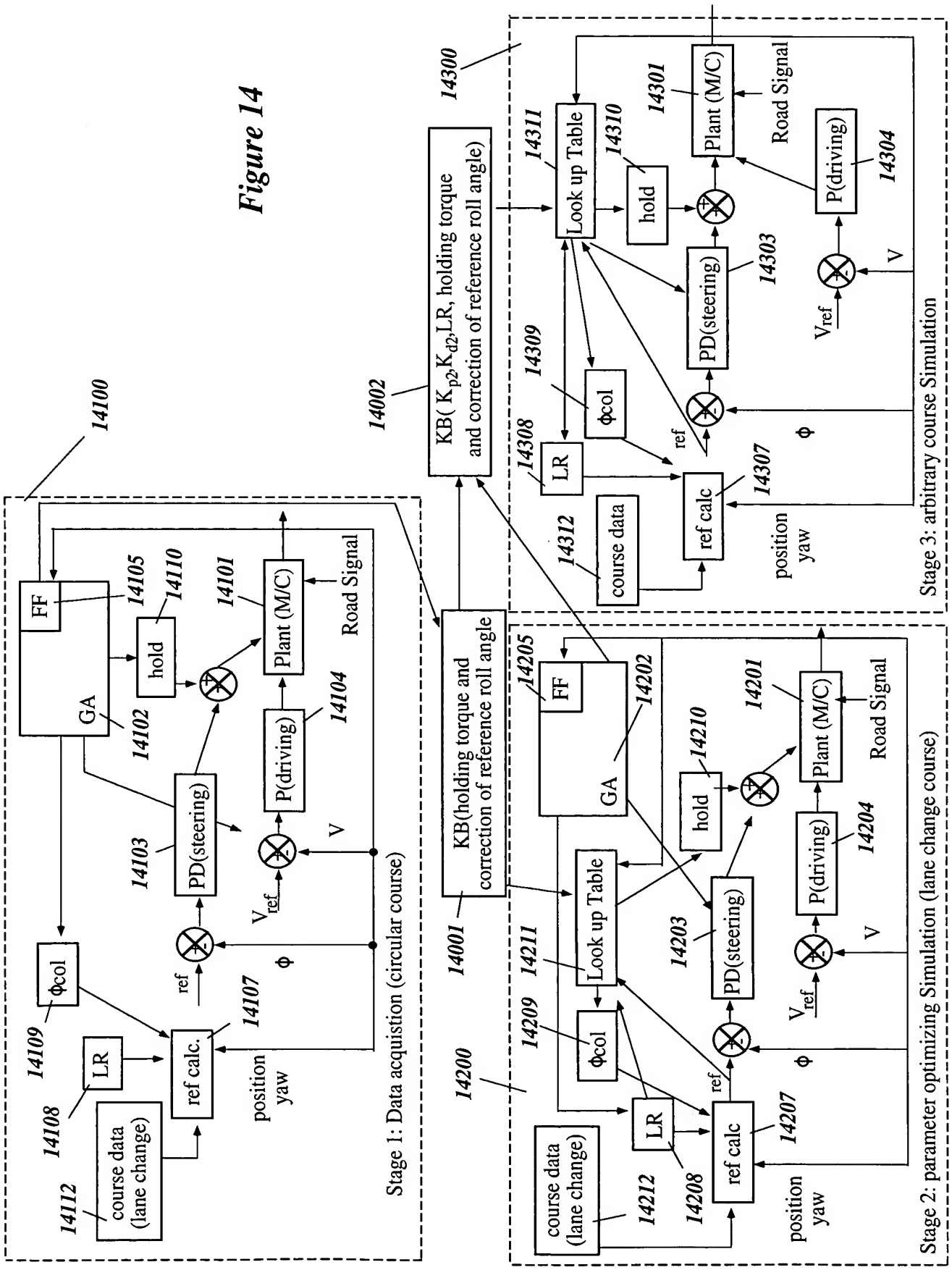

KB(K_{p1},K_{p2},K_{d2})
13002
SCO
13001
13003
KB (fuzzy rule)
FC
13206
GA
FF
13105
13102
Plant (M/C)
13101
Road Signal
P (driving)
13104
PD (steering)
13103
ref
V
ref
V
Stage 1: Teaching signal acquistion (constant velocity and Roll Simulation)
13100
Plant (M/C)
13206
Road Signal
P(driving)
13204
PD(steering)
13203
Vref
V
ref
LR
13208
ref calc.
13207
position
yaw
course data
13212
Stage 2: Arbitrary course Simulation
13200

Figure 13

Figure 14


14100
14002
14300
14001
14200
KB(K_{p2},K_{d2},LR, holding torque and correction of reference roll angle)
KB(holding torque and correction of reference roll angle
Stage 1: Data acquistion (circular course)
Stage 2: parameter optimizing Simulation (lane change course)
Stage 3: arbitrary course Simulation
course data (lane change)
course data
LR
ref calc.
ref calc
Look up Table
PD(steering)
P(driving)
hold
FF
GA
Plant (M/C)
Road Signal
ϕcol
ref
ϕ
V
V_{ref}
position
yaw
14101
14102
14103
14104
14105
14107
14108
14109
14110
14112
14201
14202
14203
14204
14205
14207
14208
14209
14210
14211
14212
14301
14303
14304
14307
14308
14309
14310
14311
14312

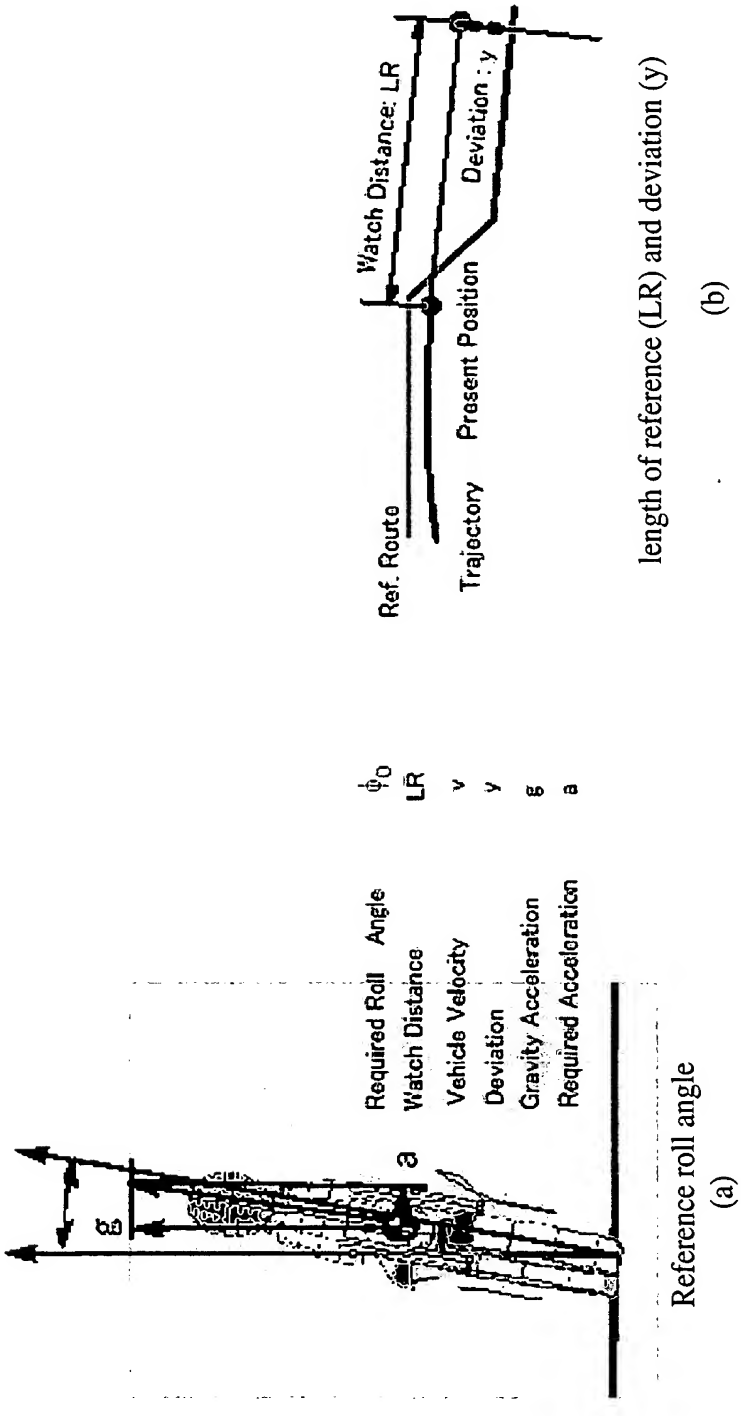

Watch Distance: LR
Deviation : y
Present Position
Trajectory
Ref. Route
length of reference (LR) and deviation (y)
(b)
Required Roll Angle
Watch Distance
Vehicle Velocity
Deviation
Gravity Acceleration
Required Acceleration
a
g
Reference roll angle
(a)

Figure 15

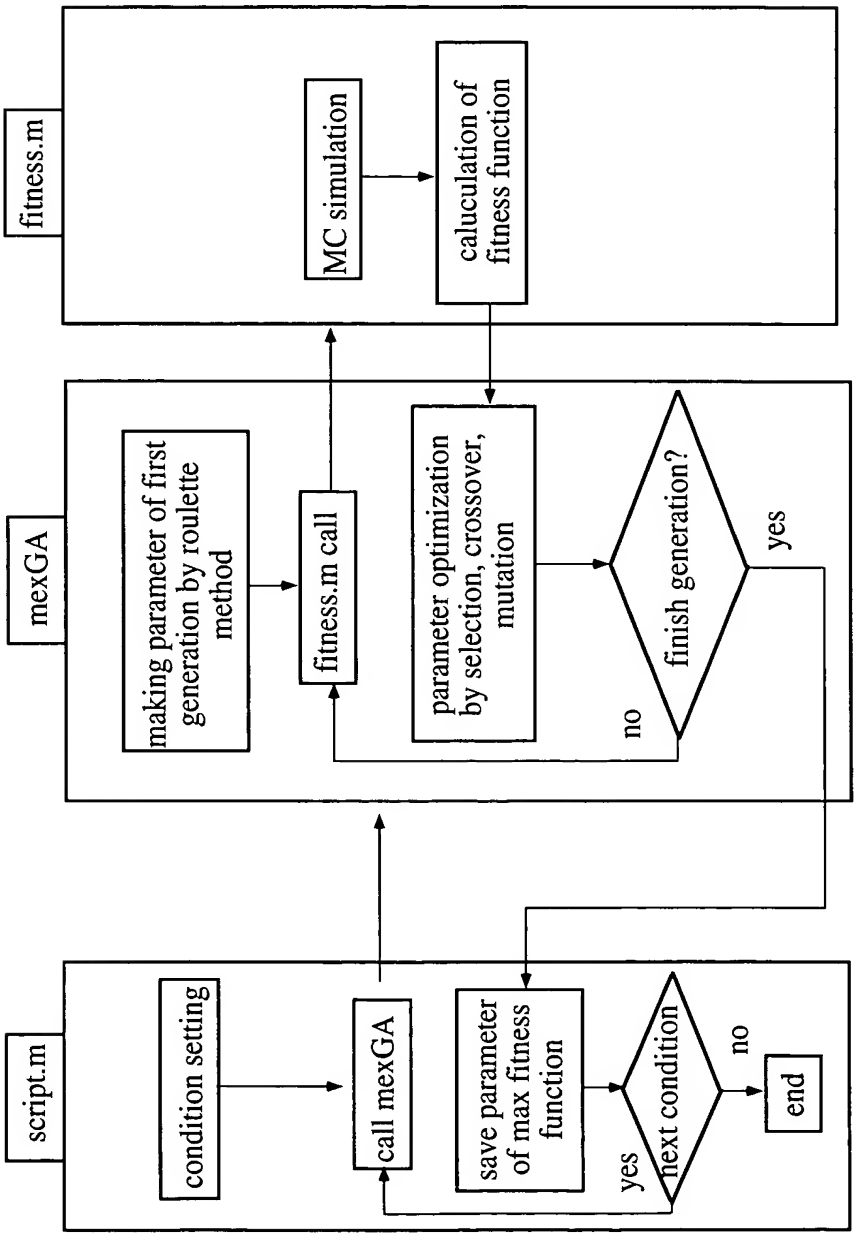

fitness.m
MC simulation
caluculation of fitness function
mexGA
making parameter of first generation by roulette method
fitness.m call
parameter optimization by selection, crossover, mutation
finish generation?
yes
no
script.m
condition setting
call mexGA
save parameter of max fitness function
next condition
yes
no
end

Figure 16

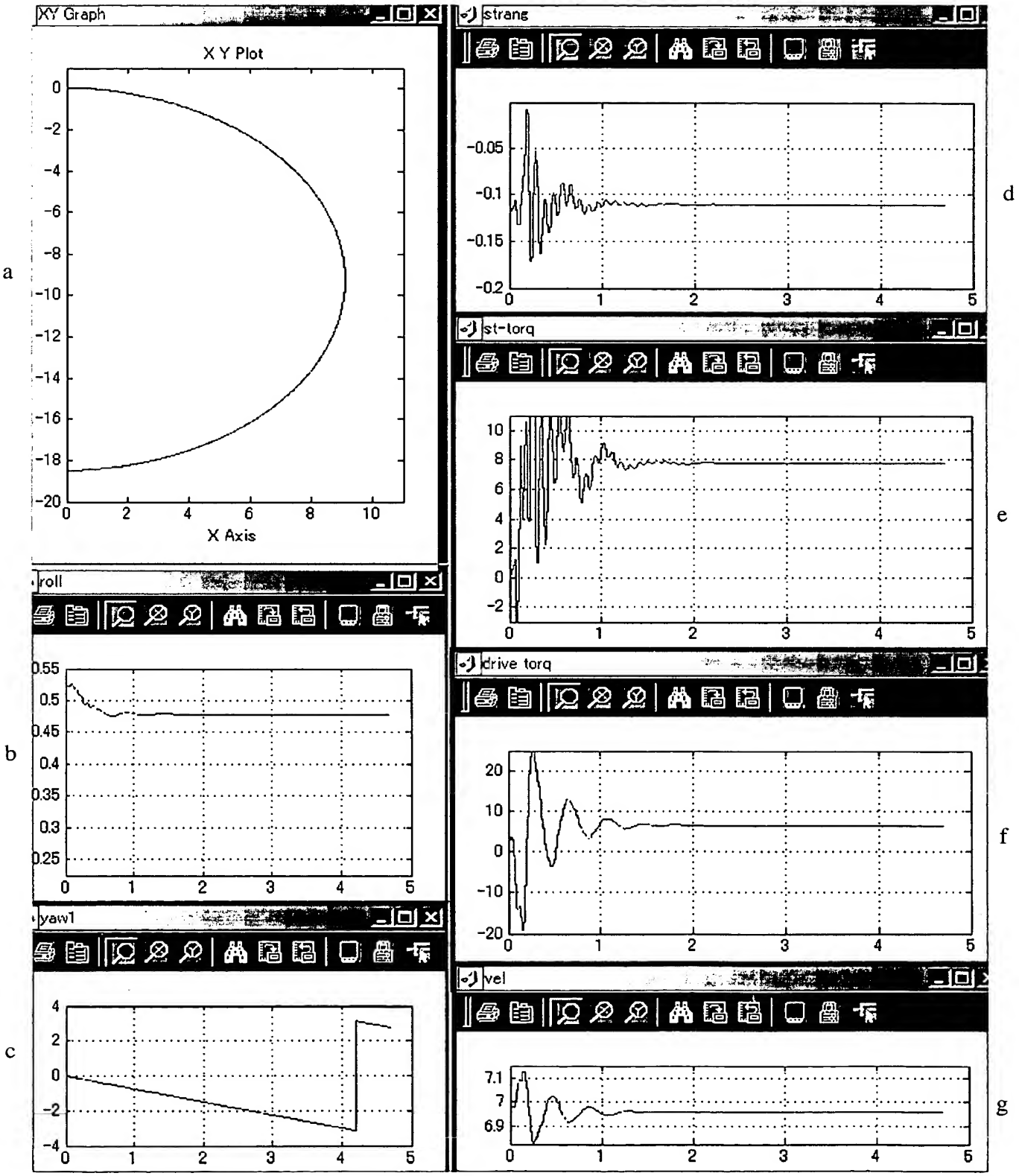

XY Graph
X Y Plot
X Axis
a
roll
b
yaw1
c
strang
d
st-torq
e
drive torq
f
vel
g

Figure 17

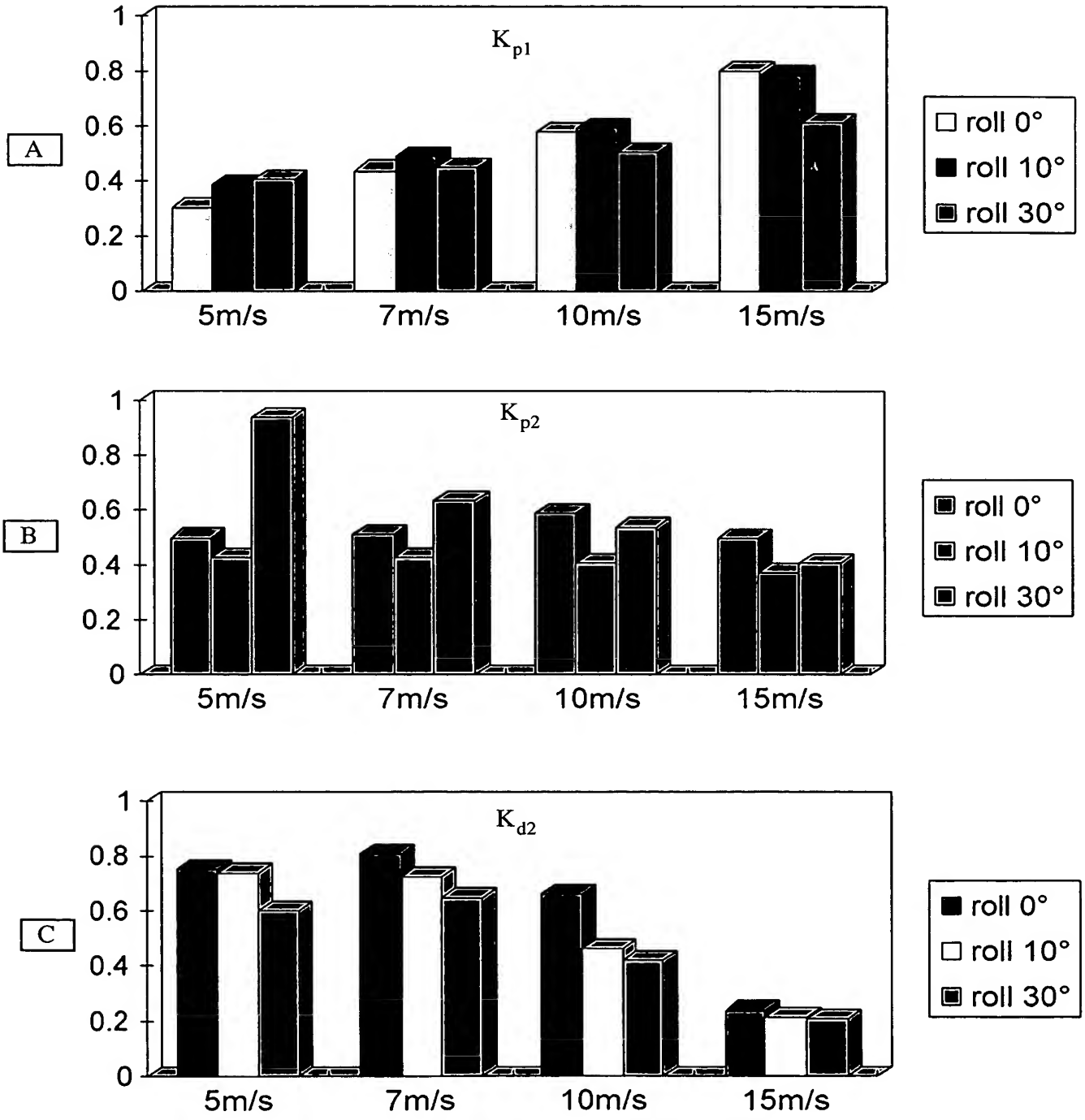

A
K_{p1}
1
0.8
0.6
0.4
0.2
0
5m/s
7m/s
10m/s
15m/s
roll 0°
roll 10°
roll 30°
B
K_{p2}
1
0.8
0.6
0.4
0.2
0
5m/s
7m/s
10m/s
15m/s
roll 0°
roll 10°
roll 30°
C
K_{d2}
1
0.8
0.6
0.4
0.2
0
5m/s
7m/s
10m/s
15m/s
roll 0°
roll 10°
roll 30°

Figure 18

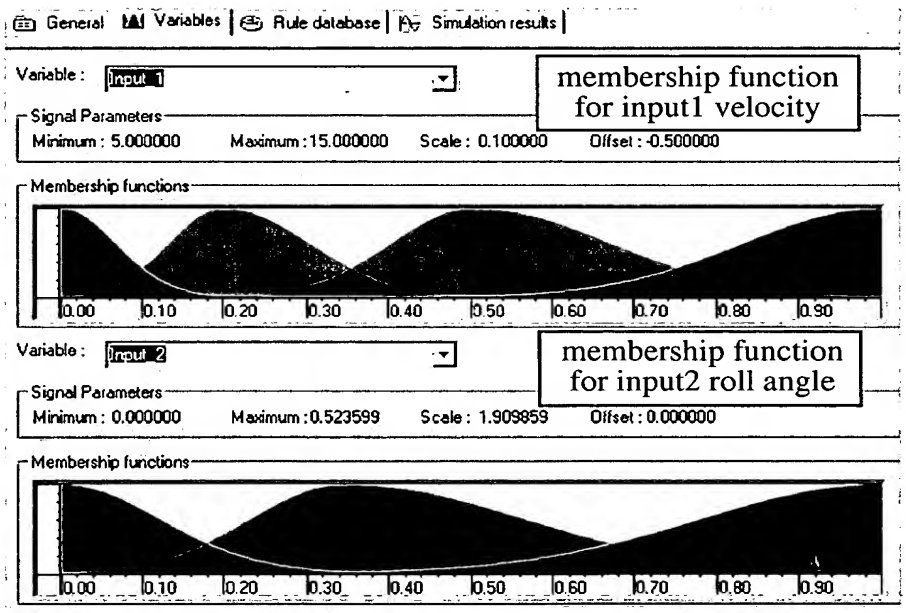
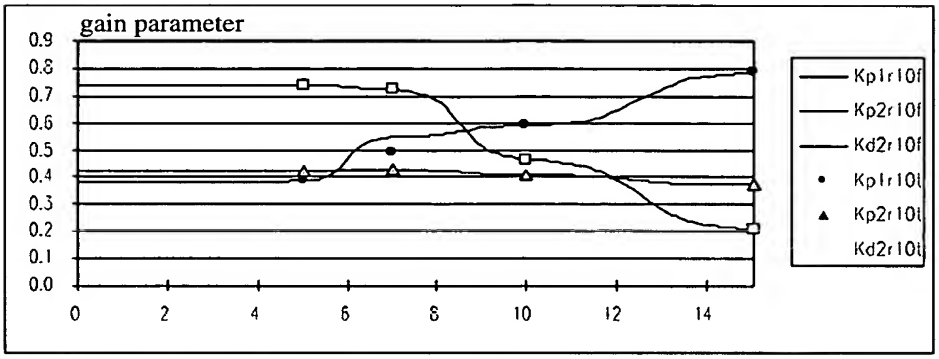
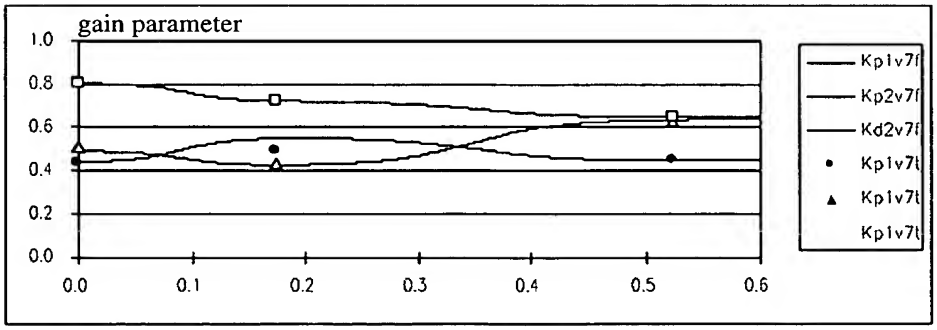

General
Variables
Rule database
Simulation results
Variable : input 1
membership function for input1 velocity
Signal Parameters
Minimum : 5.000000
Maximum : 15.000000
Scale : 0.100000
Offset : -0.500000
Membership functions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Variable : input 2
membership function for input2 roll angle
Signal Parameters
Minimum : 0.000000
Maximum : 0.523599
Scale : 1.909859
Offset : 0.000000
Membership functions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90

Figure 19



a

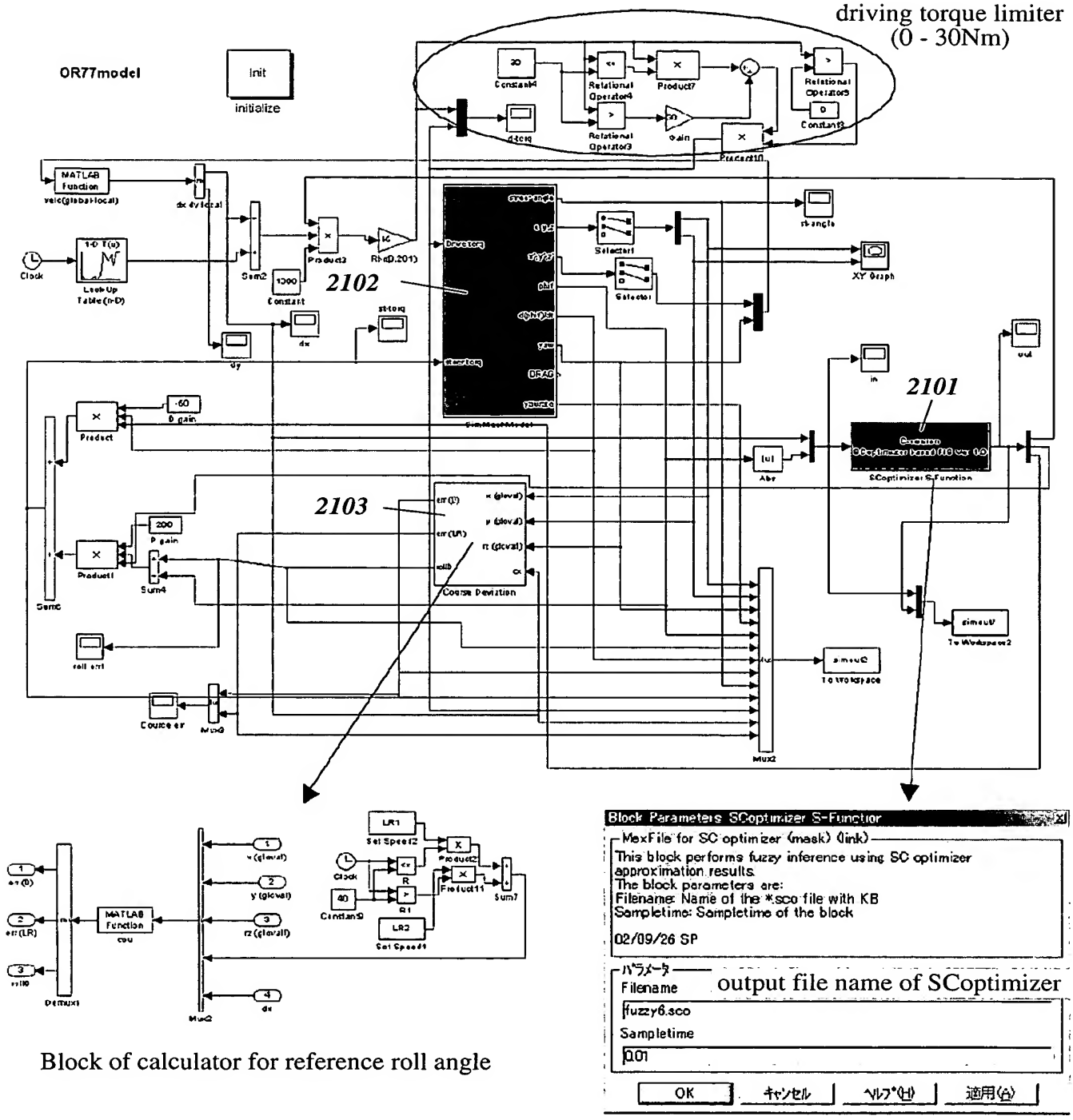
Lines: Fuzzy controller output (roll 10 deg)
point: Teaching signal (roll 10 deg)



b

Lines: Fuzzy controller output (vel. 7 m/s)
point: Teaching signal (vel. 7 m/s)

Figure 20



Block of calculator for reference roll angle

Figure 21

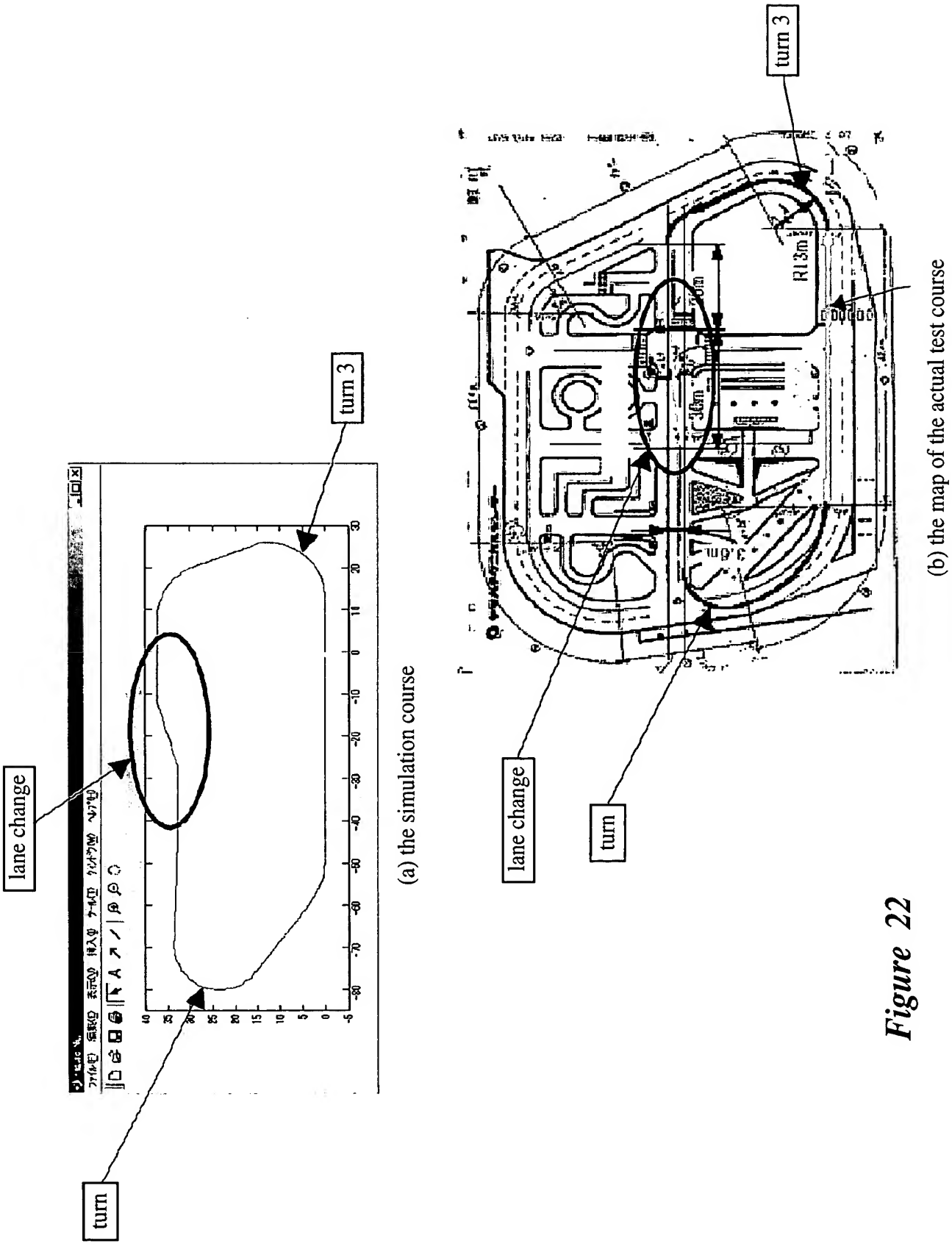
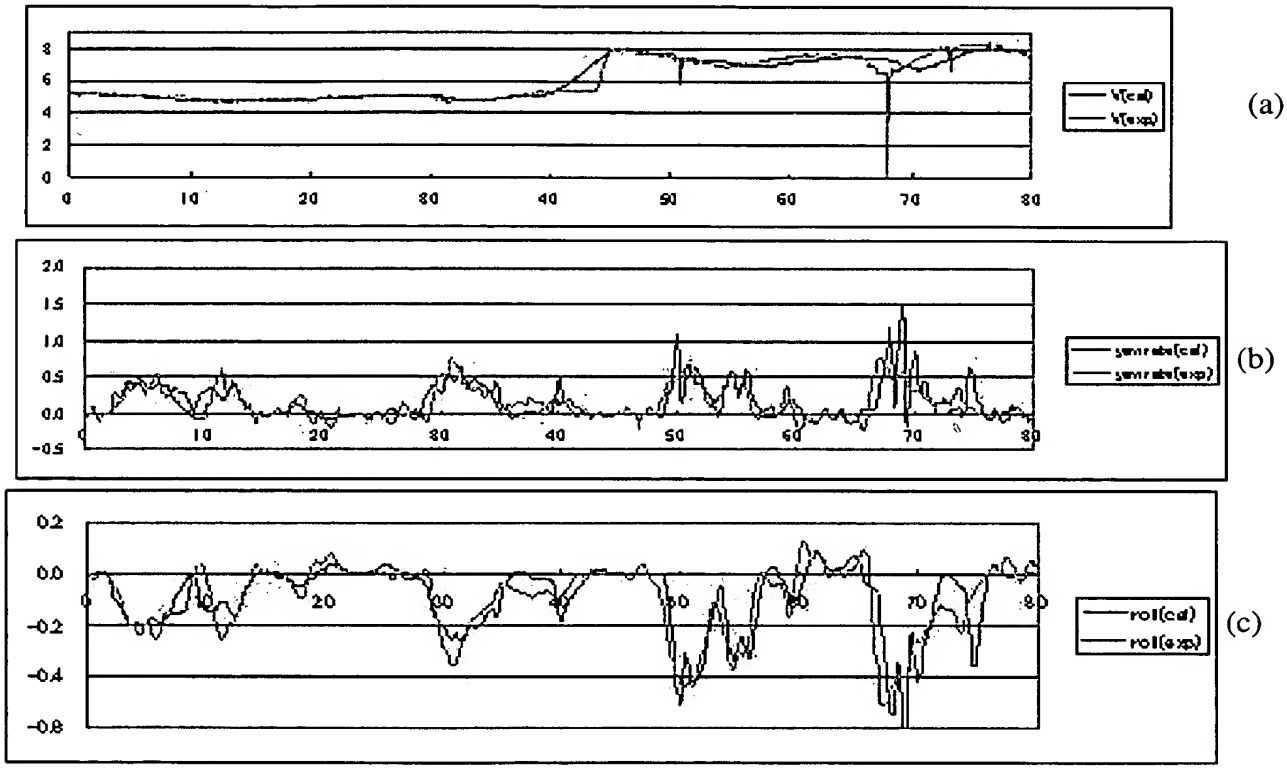

turn 3
lane change
turn
(a) the simulation course
turn 3
lane change
turn
(b) the map of the actual test course

Figure 22



(a)

(b)

(c)

Figure 23
(a-c from above)

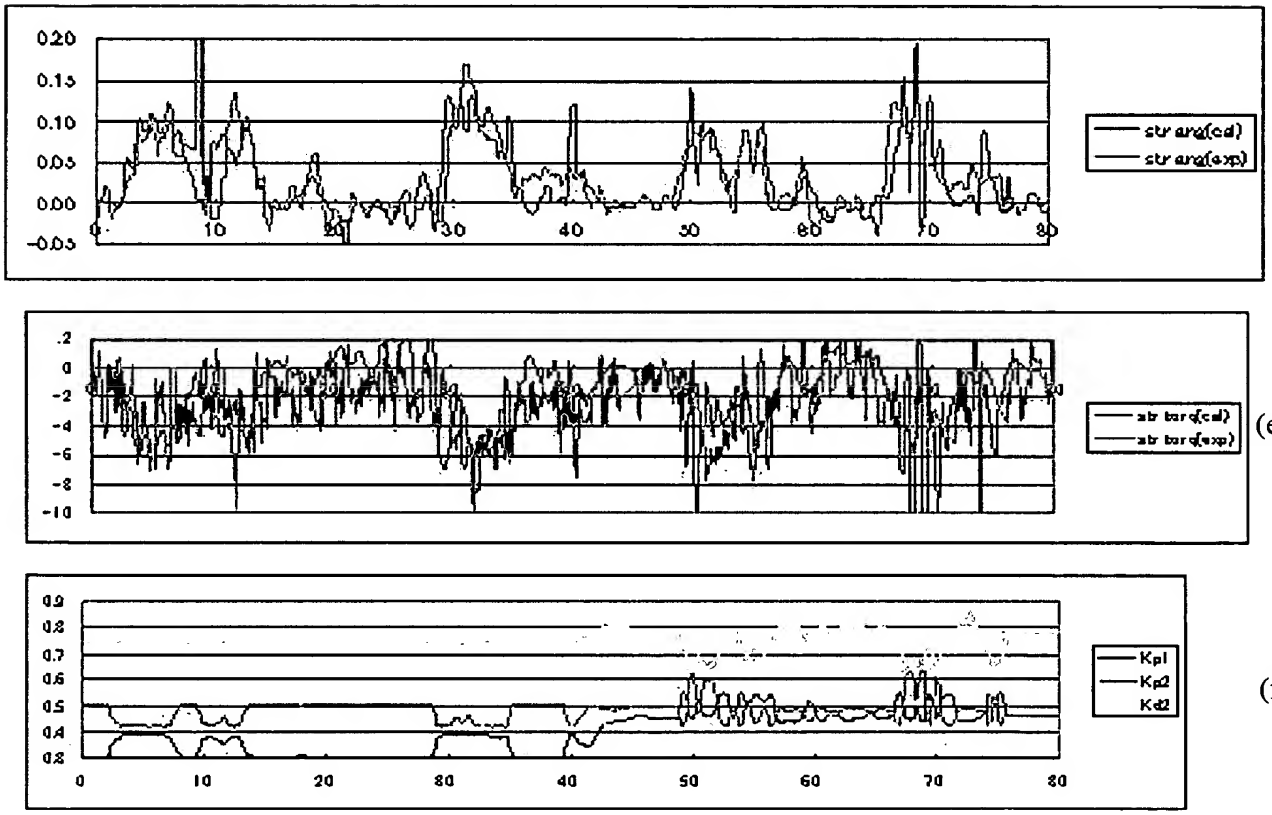


Figure 23

(d-f from above)

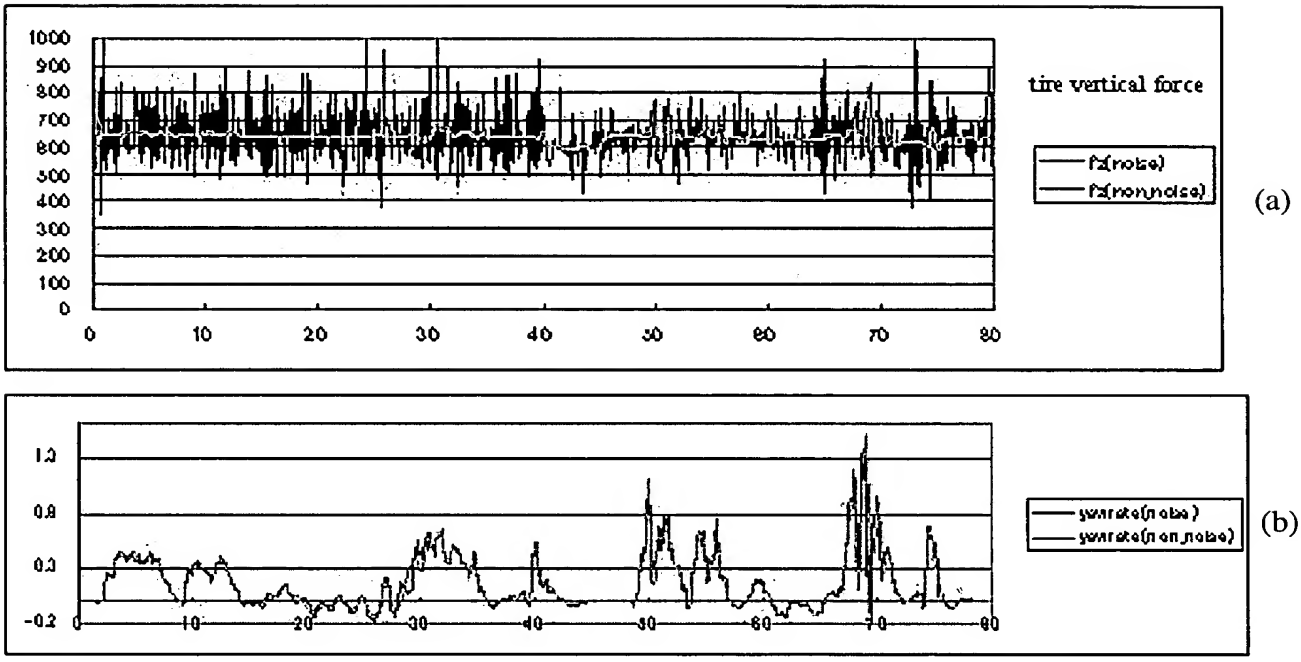


Figure 24

(a-b from above)

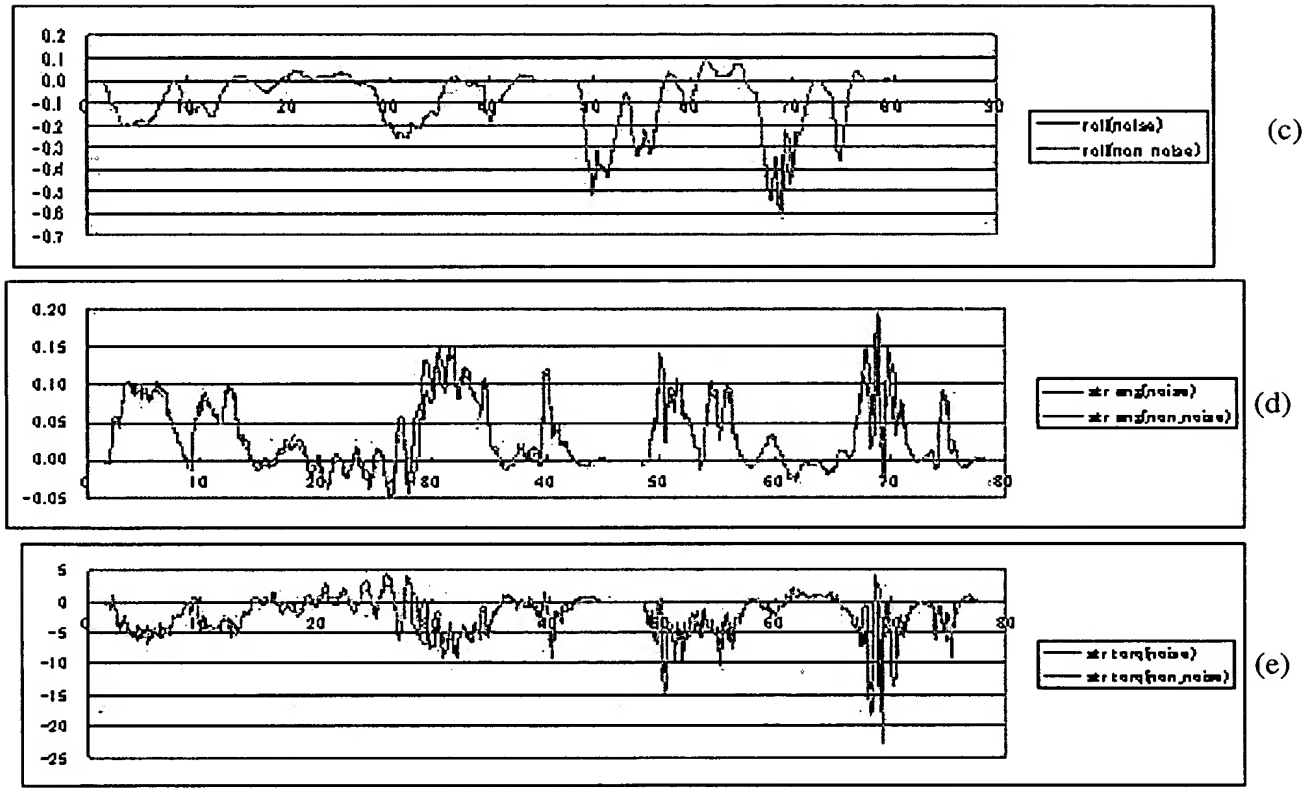


Figure 24

(c-e from above)

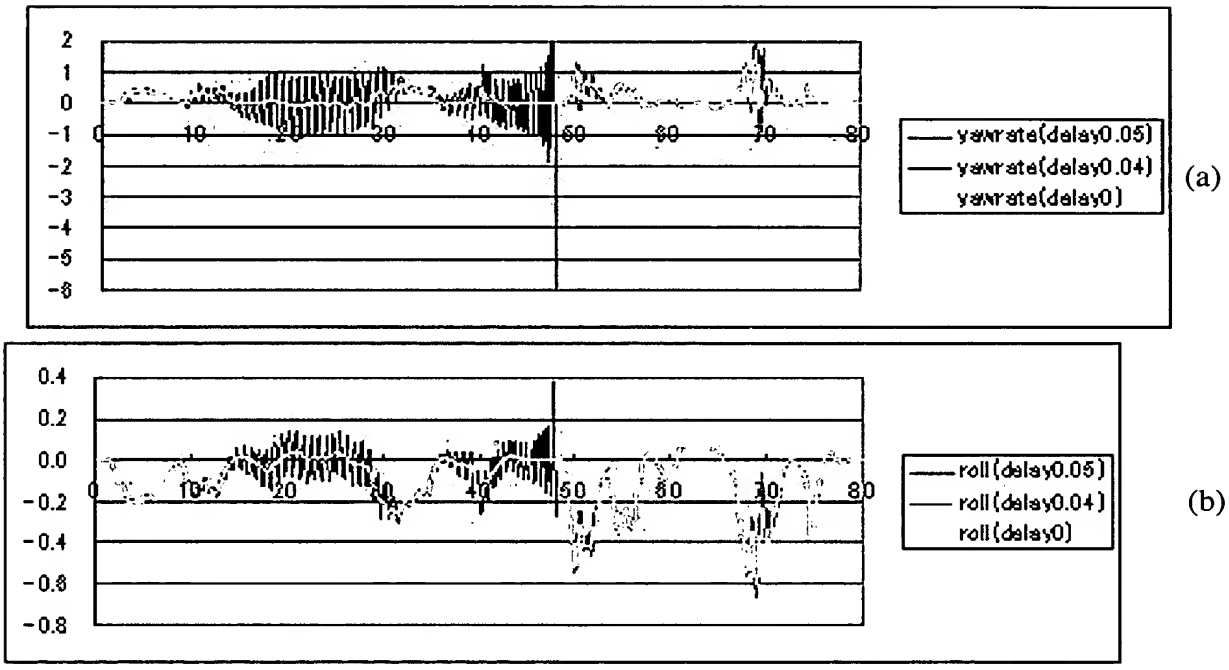


Figure 25

(a-b from above)

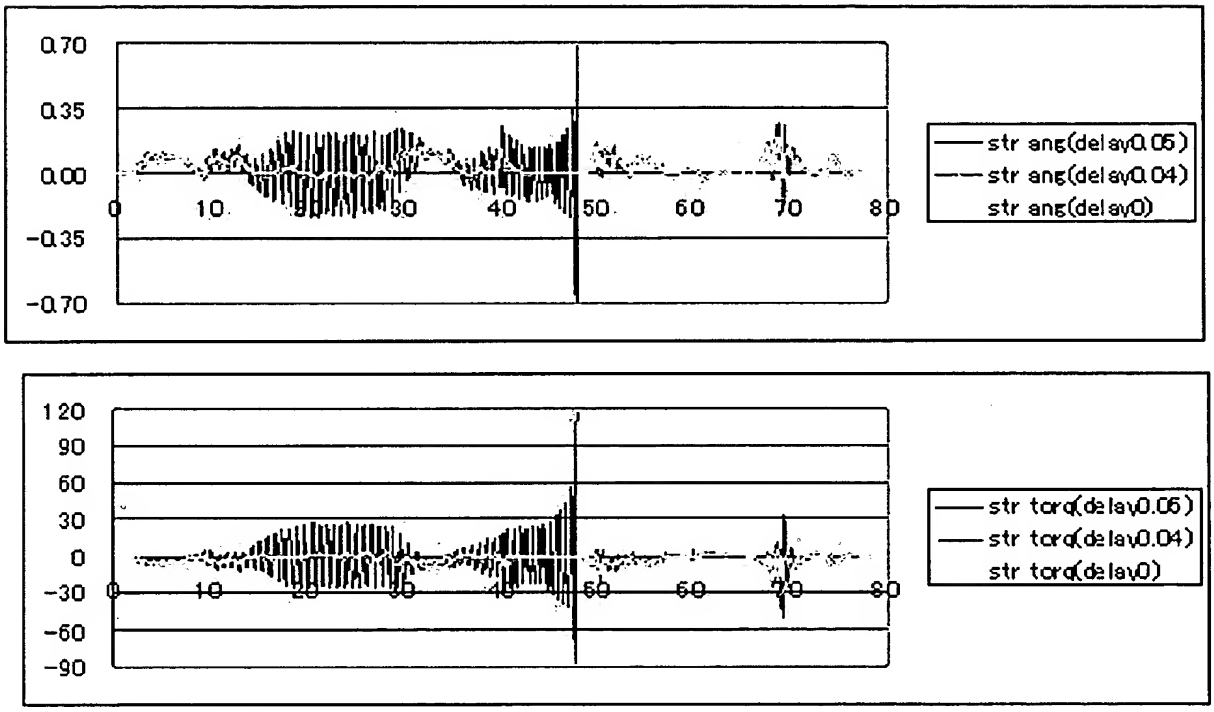
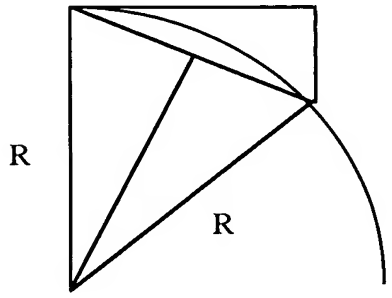
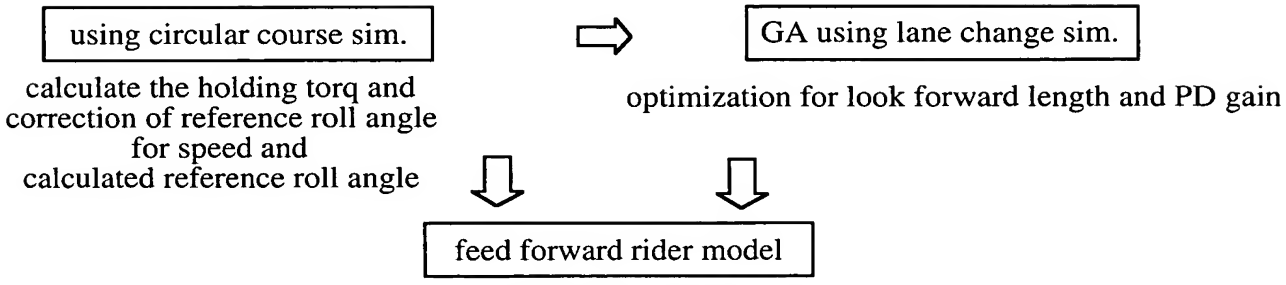


Figure 25
(c-d from above)



(a) Relation between
deviation of course at length of reference
and turning radius



(b) Process of making feed forward rider model

Figure 26

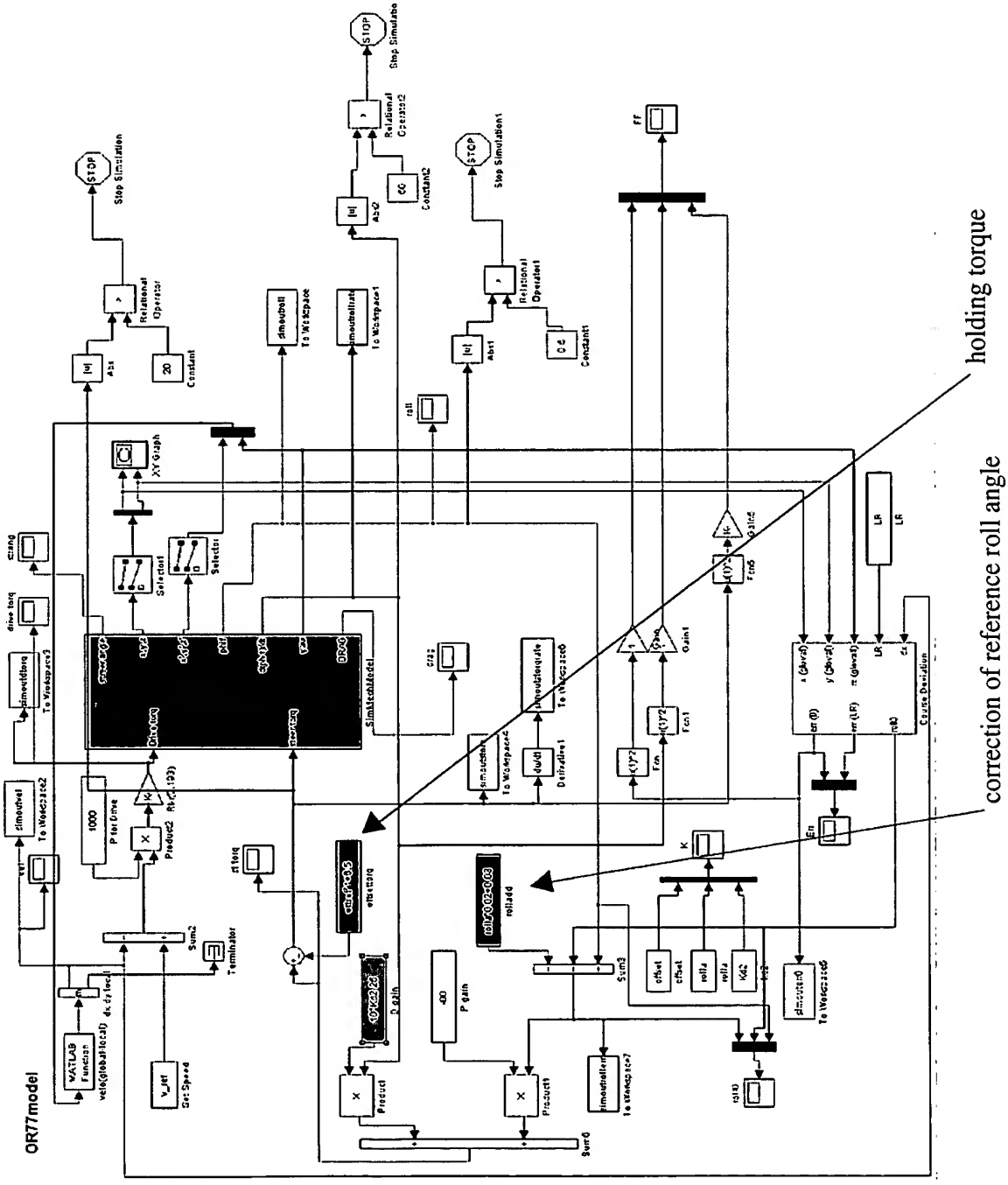

holding torque
correction of reference roll angle
OR77model

Figure 27

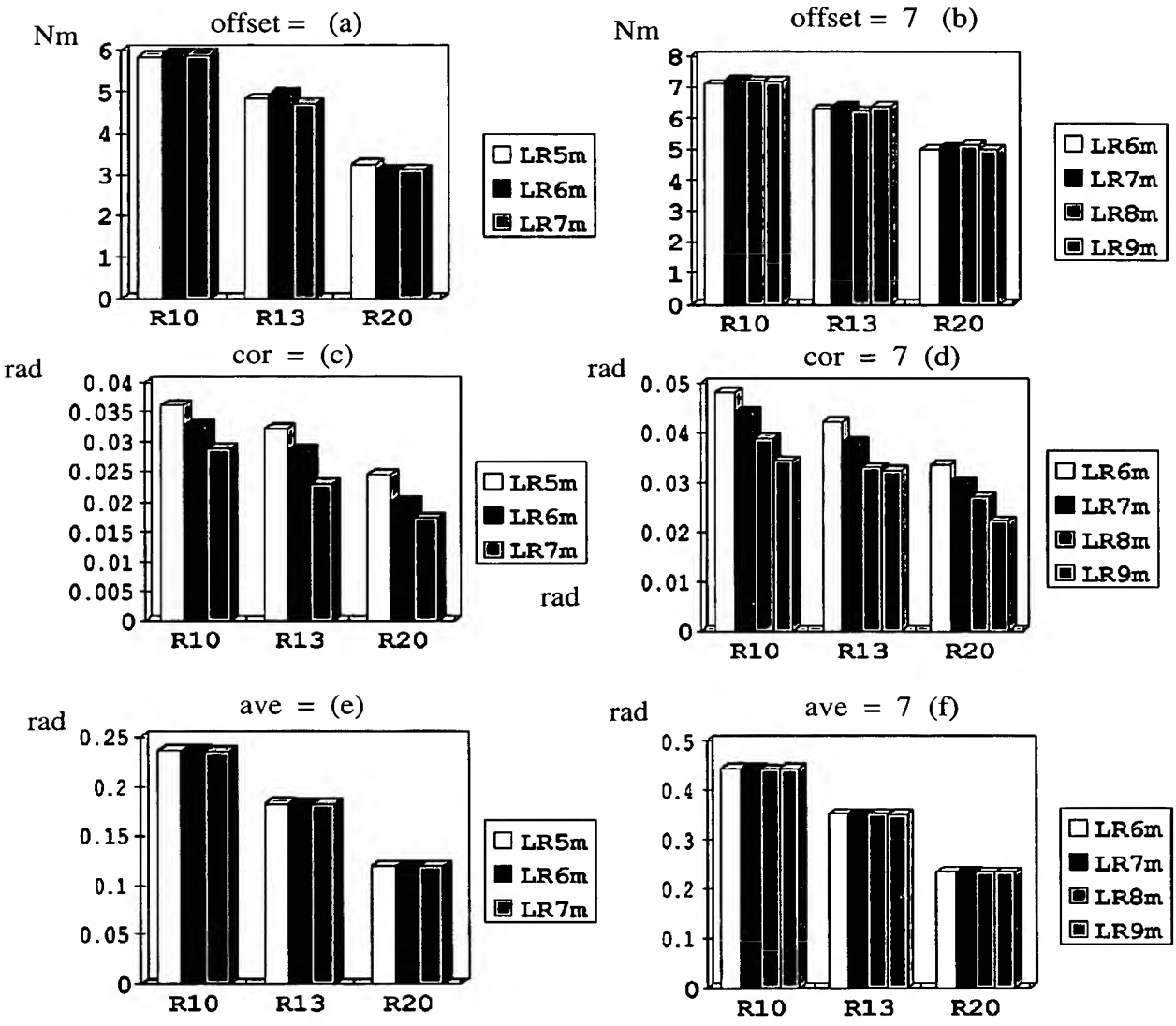

Nm
offset = (a)
R10
R13
R20
LR5m
LR6m
LR7m
Nm
offset = 7 (b)
LR6m
LR7m
LR8m
LR9m
rad
cor = (c)
rad
cor = 7 (d)
rad
ave = (e)
rad
ave = 7 (f)

Figure 28 (a-f)

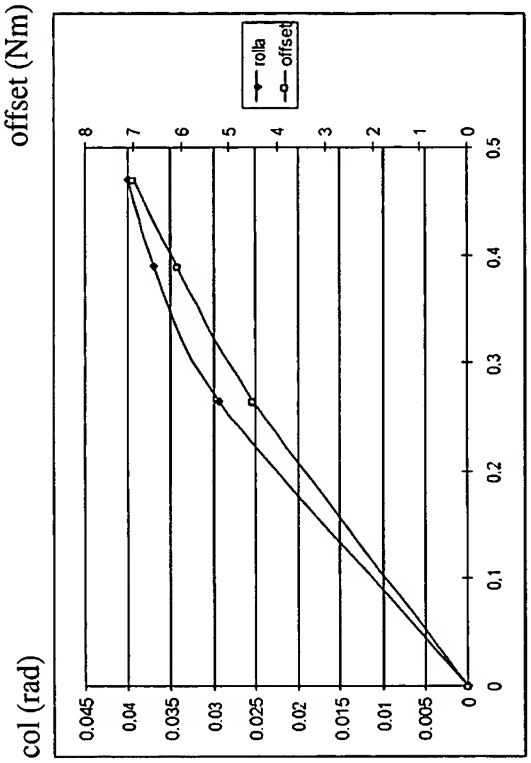


Figure 29B

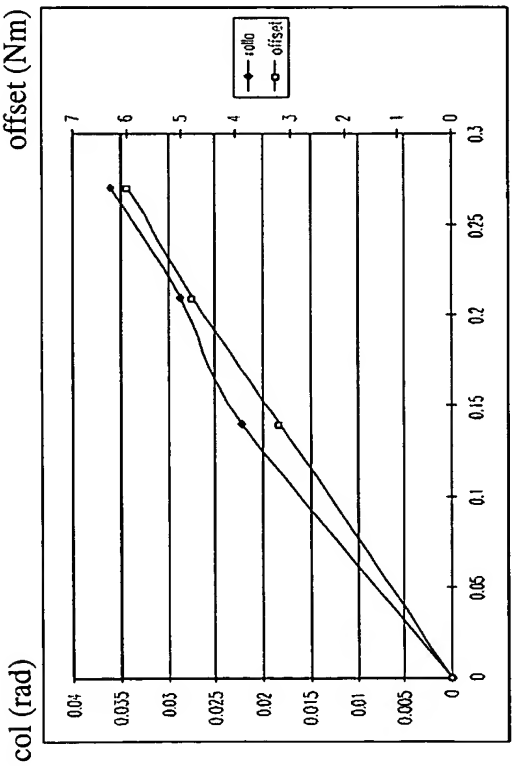


Figure 29A

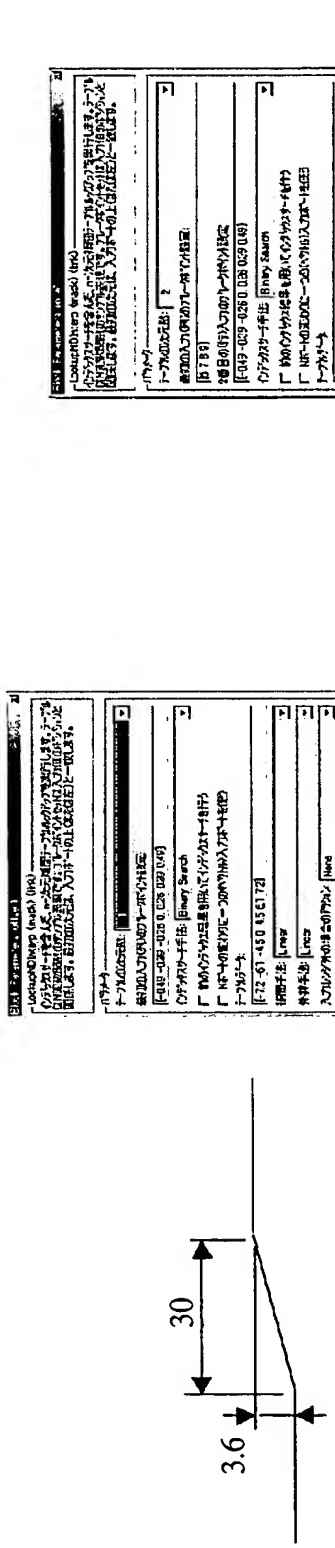


Figure 30 (a)
Course of lane change

Figure 30 (b)
Model for lane change simulation

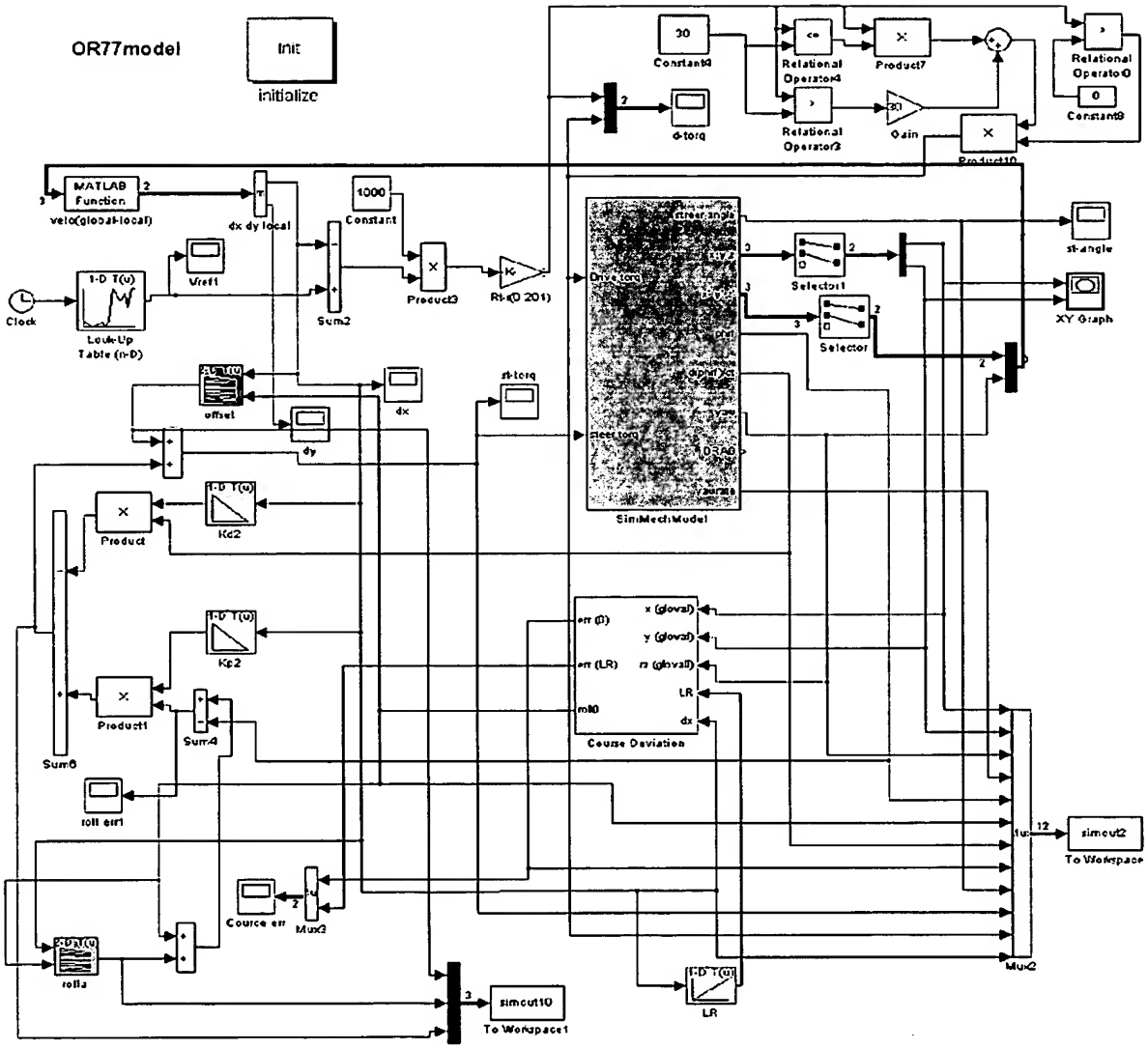

OR77model
Init
initialize
Constant4
Relational Operator4
Product7
Relational Operator0
Constant9
d-torq
Relational Operator2
0.sin
MATLAB Function
velo(global-local)
dx dy local
1000
Constant
Vref1
Clock
1-D T(u)
Look-Up Table (n-D)
Sum2
Product3
Rate(0.201)
Drive torq
Fleet torq
SimMechModel
Selector1
Selector
st-angle
XY Graph
offset
dx
dy
st-torq
Product
Kd2
Kp2
Product1
Sum4
Sum6
roll err1
Cource err
Mux3
roll a
simout10
To Workspace1
Cource Deviation
err (d)
err (LR)
mi0
x (global)
y (global)
rr (global)
LR
dx
LR
Mux2
simout2
To Workspace

Figure 31

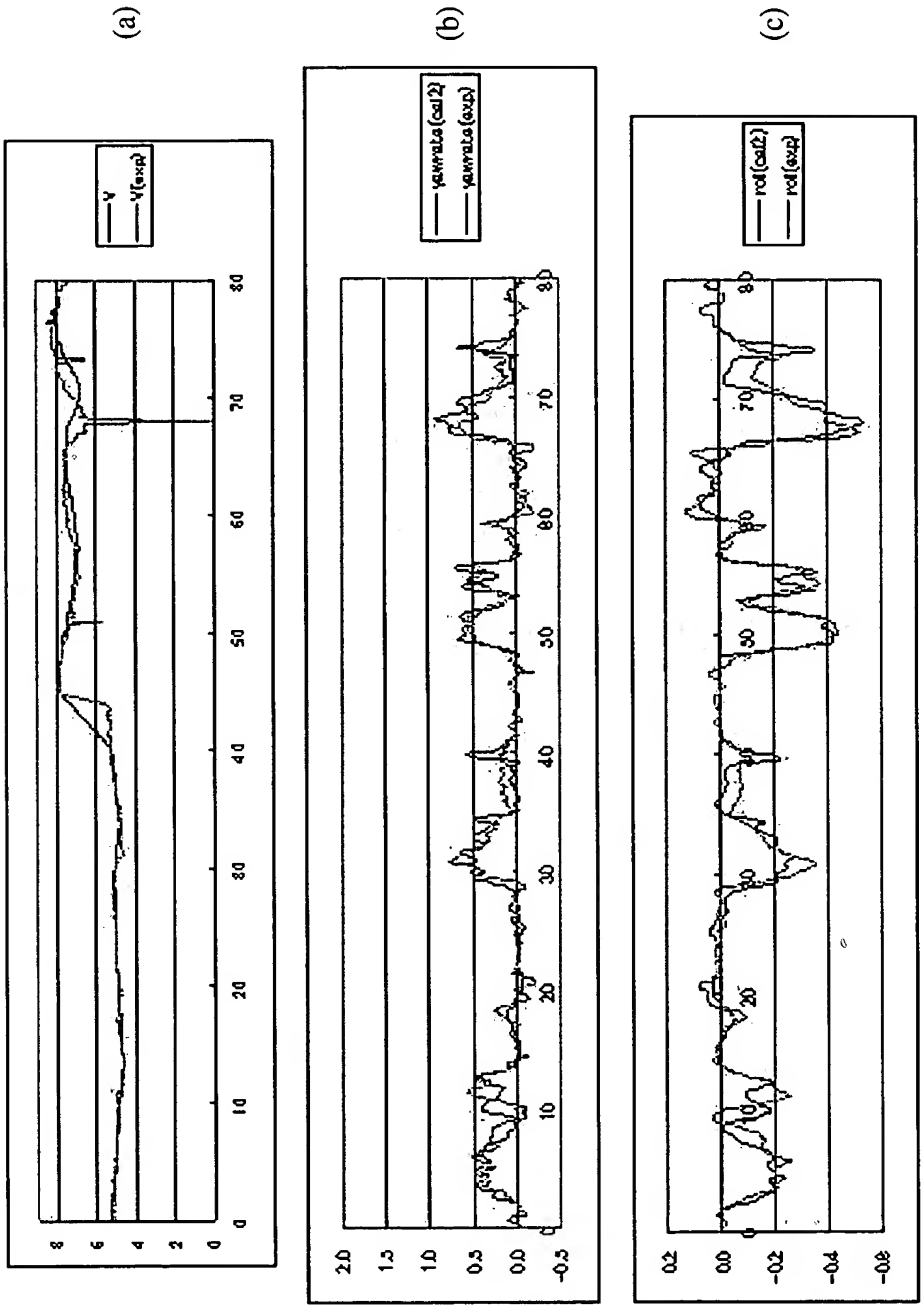


Figure 32
(a-c from above)

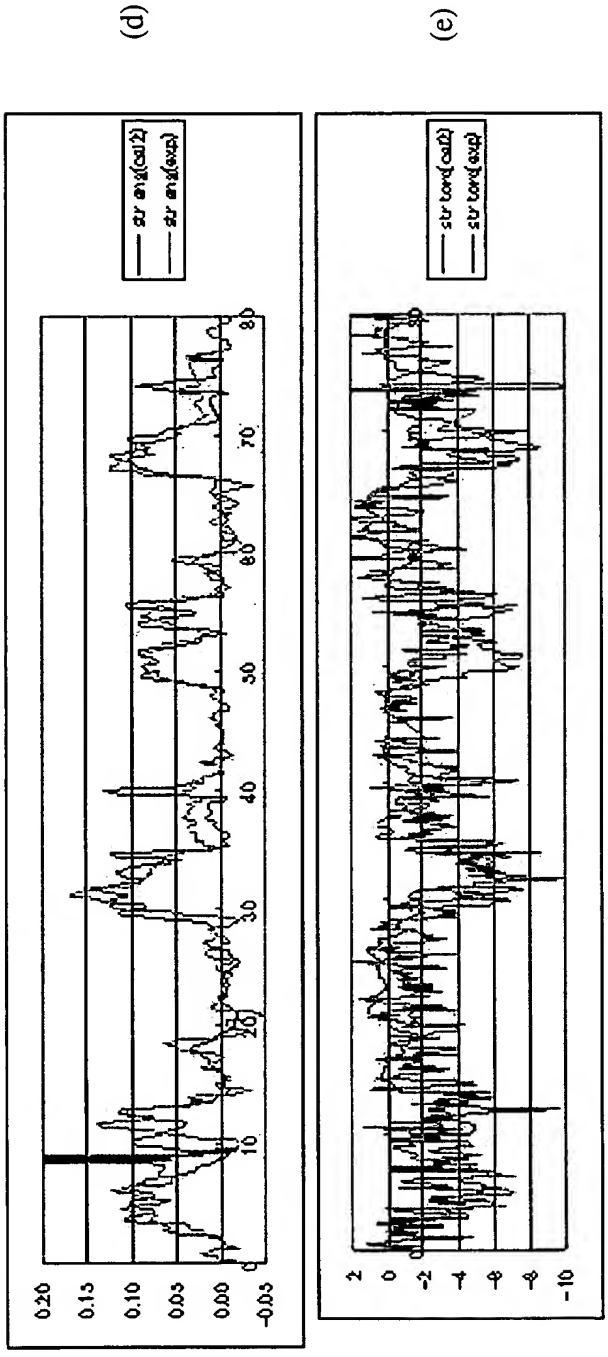


Figure 32
(d-e from above)

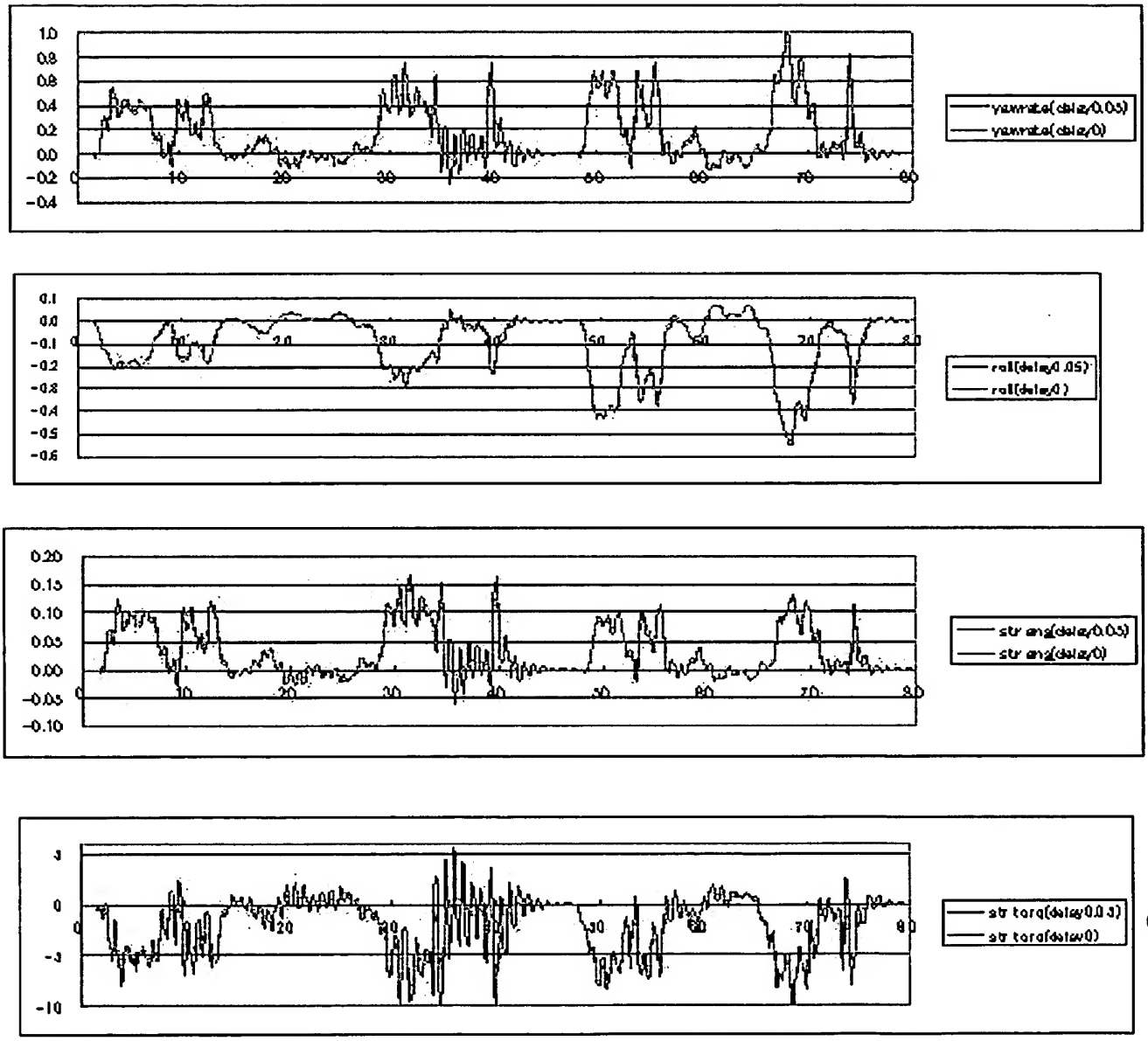


Figure 33

(a-d from above)

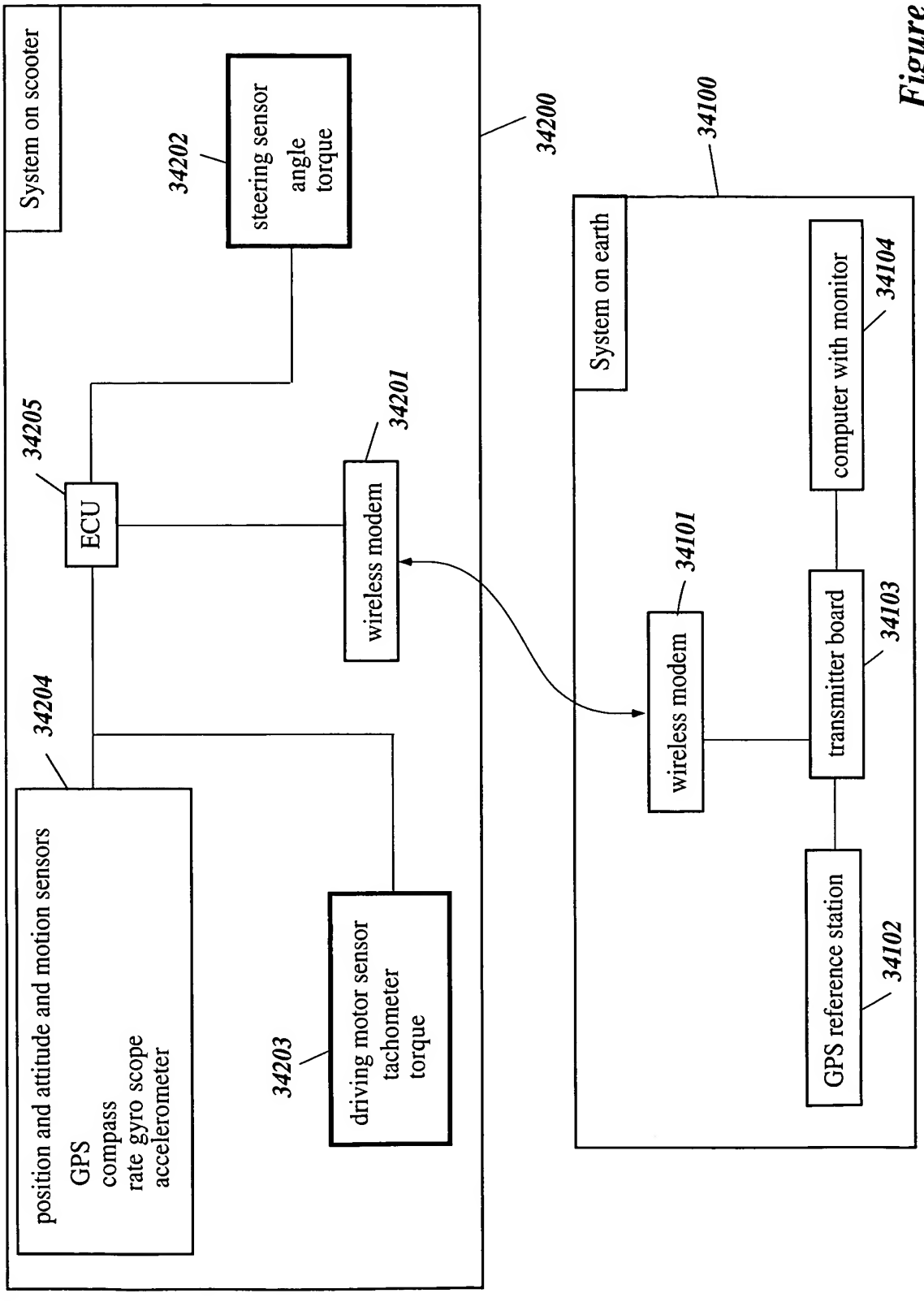

System on scooter
34200
34202
steering sensor
angle
torque
34205
ECU
34201
wireless modem
34204
position and attitude and motion sensors
GPS
compass
rate gyro scope
accelerometer
34203
driving motor sensor
tachometer
torque
34100
System on earth
34101
wireless modem
34103
transmitter board
34104
computer with monitor
34102
GPS reference station

Figure 34

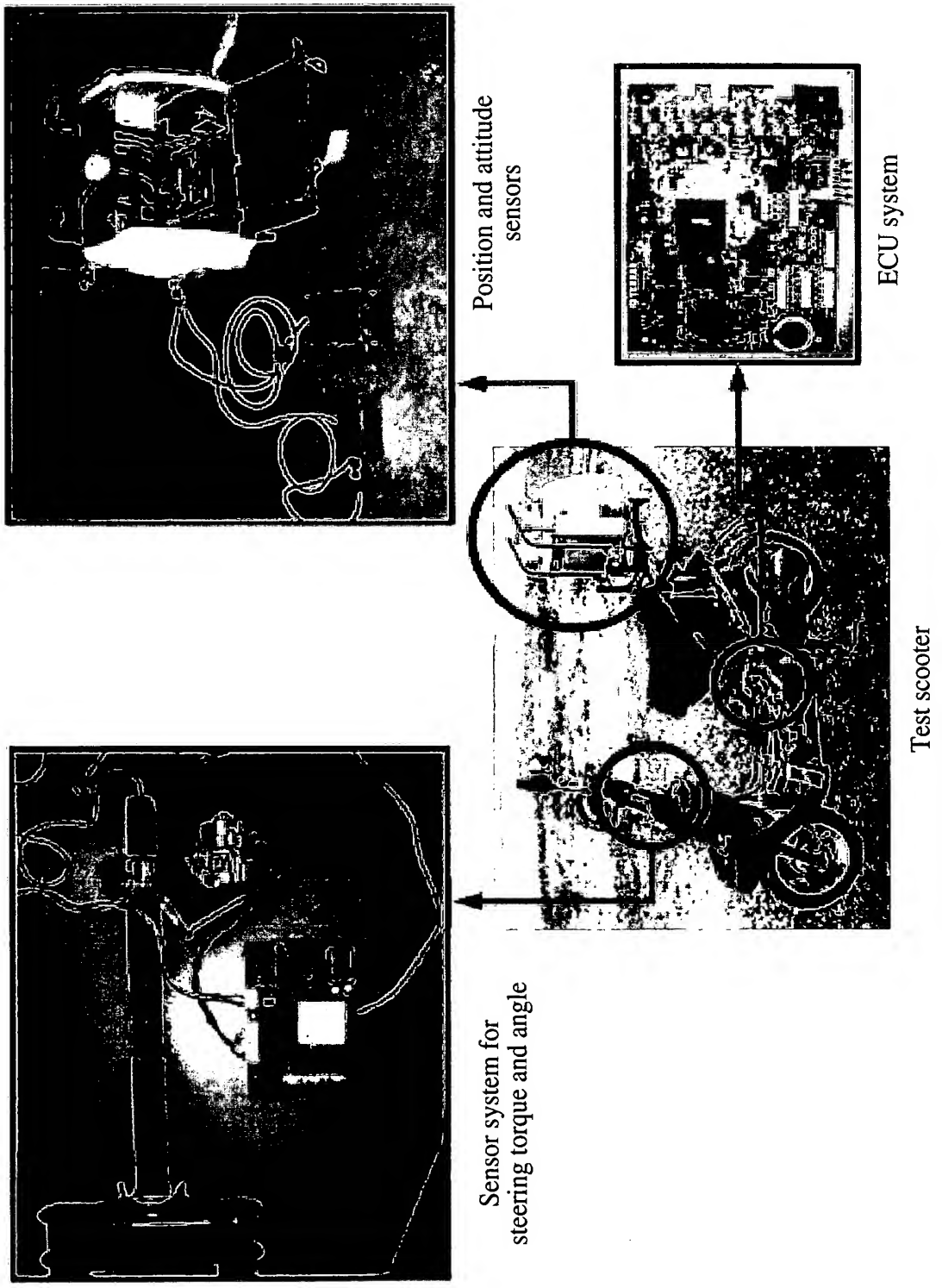
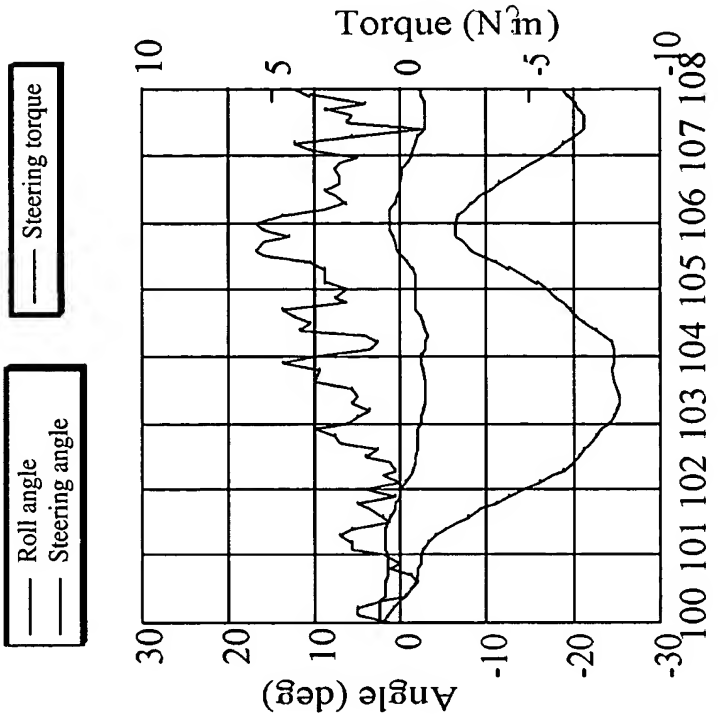
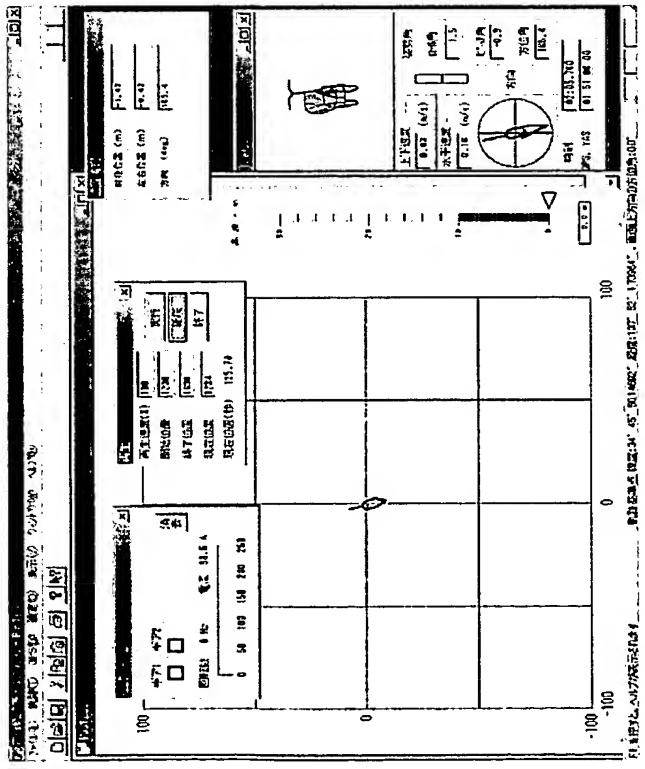

Position and attitude sensors
ECU system
Test scooter
Sensor system for steering torque and angle

Figure 35



(b) Measured data



(a) Realtime monitor of position and attitude

Figure 36